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ABSTRACT

This volume of student materials for a secondary/postsecondary level course in principles of marine diesel engines is one of a number of military-developed curriculum packages selected for adaptation to vocational instruction and curriculum development in a civilian setting. The purpose of the individualized, self-paced course is to acquaint students with the operating cycles and systems that make up a diesel engine. It provides theory that is useful in laboratory and on-the-job learning experiences. The course is divided into two lessons: Diesel Engine Construction, Principles, and Structural Parts; and Valve Gear, Fuel Injection, and Governors. These materials are included: the reference text, "Basic Principles of Marine Diesel Engines" (five chapters and an appended glossary); and a student workbook that details lesson objectives, reading assignments from the text, review exercises, and review exercise answer keys. A course examination is included, but no answers are provided. (YLB)

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The course materials were acquired, evaluated by project staff and practitioners in the field, and prepared for dissemination. Materials which were specific to the military were deleted, copyrighted materials were either omitted or approval for their use was obtained. These course packages contain curriculum resource materials which can be adapted to support vocational instruction and curriculum development.

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This project, funded by the U.S. Office of Education, includes the identification and acquisition of curriculum materials in print form from the Coast Guard, Air Force, Army, Marine Corps and Navy.

Access to military curriculum materials is provided through a "Joint Memorandum of Understanding" between the U.S. Office of Education and the Department of Defense.

The acquired materials are reviewed by staff and subject matter specialists, and courses deemed applicable to vocational and technical education are selected for dissemination.

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Project Staff:

Wesley E. Budke, Ph.D., Director
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- Communications
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Rebecca S. Douglass
Director
100 North First Street
Springfield, IL 62777
217/782-0759

NORTHWEST
William Daniels
Director
Building 17
Airdustrial Park
Olympia, WA 98504
206/753-0879

MIDWEST
Robert Patton
Director
1515 West Sixth Ave.
Stillwater, OK 74704
405/377-2000

SOUTHEAST
James F. Shill, Ph.D.
Director
Mississippi State University
Drawer DX
Mississippi State, MS 39762
601/325-2510

NORTHEAST
Joseph F. Kelly, Ph.D.
Director
225 West State Street
Trenton, NJ 08625
609/292-6562

WESTERN
Lawrence F. H. Zane, Ph.D.
Director
1776 University Ave.
Honolulu, HI 96822
808/948-7834

BASIC PRINCIPLES OF MARINE DIESEL ENGINES

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BASIC PRINCIPLES OF MARINE DIESEL ENGINES

Correspondence Course 8-2

1

Developed by:

United States Army

Development and Review Dates

Unknown

Occupational Area:

Engine Mechanics

Cost:	**Print Pages:**
$2.25	102

Availability:

Military Curriculum Project, The Center for Vocational Education, 1960 Kenny Rd., Columbus, OH 43210

Suggested Background:

None

Target Audiences:

Grades 10-adult

Organization of Materials:

Reference text; lesson exercises with objectives, lesson assignments, and review exercises; course examination with answers to the lesson exercises

Type of Instruction:

Individualized, self-paced

Type of Materials:		**No. of Pages:**	**Average Completion Time:**
Basic Principles of Marine Diesel Engines			
Lesson 1 –	Diesel Engine Construction, Principles and Structural Parts	39	Flexible
Lesson 2 –	Valve Gear, Fuel Injection, and Governors	27	Flexible
Lesson Exercises		9	
Examination		5	

Supplementary Materials Required:

None

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Course Description:

This basic course is designed to acquaint the student with the operating cycles and systems that make up a diesel engine. It provides the theory which might be useful in a laboratory or on-the-job learning situation.

This course is divided into two lessons covering five chapters from the text.

Lesson 1 – *Diesel Engine Construction, Principles and Structural Parts* discusses the construction of the diesel engine, principles of four-stroke and two-stroke cycles, combustion, main stationary parts, and main moving parts.

Lesson 2 – *Valve Gear, Fuel Injection, and Governors* discusses cams, camshaft, cam followers; rocker arms and push rods; valves, valve springs, and valve lash and adjustment; the requirements of fuel injection systems; common rail and individual-pump injector systems; fuel nozzles and unit injectors; the distributor systems; and the types and operating principles of governors.

This course is designed for student self-study. The student workbook provides lesson objectives, reading assignments from the text and review exercises. The text is coded and the answers to the review exercise are keyed to the text for student self-evaluation. A course examination is provided, but no answers are available.

REFERENCE TEXT
475

BASIC PRINCIPLES OF MARINE DIESEL ENGINES

The information contained herein is provided for instructional purposes only. It reflects the current thought of this school and conforms to printed Department of the Army doctrine as closely as possible. Development and progress render such doctrine continuously subject to change.

U. S. ARMY TRANSPORTATION SCHOOL
Fort Eustis, Virginia
July 1972

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INTRODUCTION

The first diesel engine was built in Germany in 1897. Spark-ignition engines had been built commercially for 37 years. The possibility of compression ignition appears to have been first mentioned by the French scientist N. L. S. Carnot, who in 1824 published his Reflections on the Motive Power of Heat, in which he discussed the possibility of igniting fuel by compressing air to one-fourteenth of its original volume.

Nikolaus Otto built the first engine in which the charge was compressed in the cylinder before burning. This was the engine that Rudolf Diesel undertook to improve when he started experiments that led to the diesel engine.

After several years of studying the problems involved, Diesel applied for and was granted a patent in February 1892 under the title "Working Processes for Internal-Combustion Engines," and a second patent, granted a year later, that modified the cycle described. These patents were not for engine designs, but merely for the thermodynamic cycle to be followed by the gases in the engine cylinder.

Diesel's first engine was to run on pulverized coal, but this project was dropped for an oil-burning engine; after several failures, the engine ran in 1897.

The fuel economy of Diesel's engine proved to be better than that of any other existing power plant. His engine attracted considerable interest at an industrial exposition in Munich the following year, where Adolphus Busch, a U. S. brewer, saw it. Realizing its possibilities, he purchased a license from Diesel for manufacture and sale in the United States and Canada. A diesel engine built for his company in 1898 was the first to be placed in regular industrial service.

The first marine installation of a diesel engine was made in 1910, very successfully, and the diesel engine became the predominant power plant for submarines during World War I.

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This text, divided into five chapters, describes the fundamentals of marine diesel engines. The first chapter discusses diesel engine construction and principles. Structural engine parts are explained in chapter 2. The remaining three chapters cover valve gear, fuel injection, and governors respectively.

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Chapter 1

DIESEL ENGINE CONSTRUCTION AND PRINCIPLES

1.1. INTRODUCTION

Diesel engines are found in many different designs depending upon the type of vessel and its intended use. Although the outside of engines look different, the internal structure is basically the same. The first section of this chapter briefly explains the parts of a diesel engine and the various types and designs of diesel engines. The second section explains how and why diesel engines operate.

Section I. Construction

1.2. GENERAL

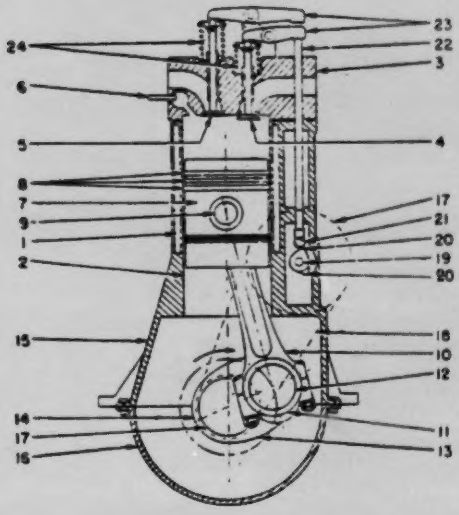
Diesel engines vary greatly in outside appearance, size, number of cylinders, cylinder arrangement, and details of construction. However, they all have the same main basic parts which may look different but perform the same functions. A diesel engine has very few basic main working parts; the rest of the engine is composed of auxiliary parts which assist the main working parts in their performance, and of connecting parts necessary to hold the working parts together. The main working parts are the cylinder, piston, connecting rod, crankshaft, bearings, and fuel pump and nozzle.

Naturally, an engine has a number of other parts without which it could not operate, but their functions are more or less subordinate and they are discussed later.

Figure 1.1 is a schematic drawing of a typical diesel engine. It shows the main working parts and their relation to other parts.

1.3. CYLINDER

The heart of the engine is the cylinder where the fuel is burned and the power developed. The inside of the cylinder is formed by the cylinder liner or sleeve, and the cylinder head which seals one end of the cylinder and often, although not always, contains



1. Cylinder.
2. Cylinder liner.
3. Cylinder head.
4. Intake valve.
5. Exhaust valve.
6. Fuel injector.
7. Piston.
8. Piston rings.
9. Wrist or piston pin.
10. Connecting rod.
11. Crankpin bearing.
12. Crankpin.
13. Crank cheek or crank web.
14. Crankshaft.
15. Engine frame.
16. Crankcase.
17. Timing chain sprocket.
18. Timing chain.
19. Camshaft.
20. Cams.
21. Cam follower.
22. Push rod.
23. Rocker arm.
24. Valve spring.

Figure 1. 1. Schematic Drawing of a Diesel Engine.

the valves to admit fuel and air and to eliminate the used gases. The interior diameter of the liner is know known as the bore.

1.4. PISTON

The piston seals the other end of the working space of the cylinder and transmits, to the outside, the power developed inside the cylinder by the burning of the fuel. A gas tight seal between the piston and the cylinder liner is produced by piston rings lubricated with engine oil. The distance that the piston travels from one end of the cylinder to the other is known as the stroke.

1.5. CONNECTING ROD

The connecting rod transmits the reciprocating motion of the piston to the continuously rotating crankshaft during the power stroke. One end, the small end of the connecting rod or conrod eye, is attached to the wrist pin or piston pin located in the piston; the other, or big end, has a bearing which encloses the crankpin.

1.6. CRANKSHAFT

The crankshaft obtains its rotary motion from the piston through the connecting rod and crankpin located between the crank webs or crank cheeks. The work of the piston is transmitted to the flywheel to reduce speed fluctuations by storing kinetic energy during the periods when power is developed and giving it back during the other periods.

1.7. CAMSHAFT

A camshaft is driven from the crankshaft by a chain drive or timing gears. Through cam followers, push rods, and rocker arms, the intake and exhaust valves are operated by cams on the camshaft. Valve springs close the valves.

1.8. CRANKCASE

A crankcase is constructed to protect the crankshaft, bearings, connecting rods, and related parts; to catch oil escaping from the bearings of the moving parts; and to provide a reservoir for lubricating oil. If the crankcase is constructed to support the whole engine, it is called a bed plate.

1.9. FUEL INJECTION

Fuel for diesel engines is delivered into the combustion space of the cylinder by an injection system consisting of a pump, fuel line, and injector, also called injection or spray nozzle.

1.10. ENGINE TYPES

Diesel engines may be divided into several classes using different bases for the division: operating cycle, cylinder arrangement, piston action, method of fuel injection, and speed, as described in subparagraphs a through e.

a. Operating cycles. Diesel engines may be divided into two groups based on the number of piston strokes per cycle, in (1) four-stroke-cycle, or for short, four-stroke engine, and (2) two-stroke-cycle, or two-stroke engine. Section II explains the meaning of these terms and the difference between these two engine types.

b. Cylinder arrangement. One of the most common ways to classify a diesel engine is by its cylinder arrangement. These types are the in-line, V-arrangement, flat, multiple-engine units, and vertical-shaft, as described in subparagraphs (1) through (5).

(1) In-line. The simplest arrangement of cylinders is the in-line arrangement, as shown in figure 1.2. This construction may be used for engines having up to eight cylinders.

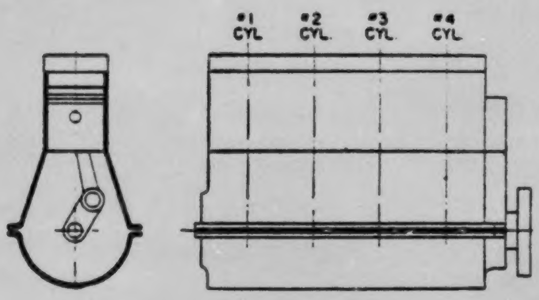


Figure 1.2. In-Line Arrangement.

(2) V-arrangement. If an engine has more than eight cylinders, it

becomes difficult to make a sufficiently rigid frame and crankshaft with an in-line arrangement. The V-arrangement, as illustrated in figure 1.3(a), with two connecting rods attached to each crankpin, permits reducing the engine length by one-half, thus making it much more rigid, with a stiff crankshaft. This is a common arrangement for engines with eight to 16 cylinders. Cylinders lying in one plane are called a bank. In figure 1.3(a), the angle "a" between the banks may vary from 30° to 120°, the most common angle being between 40° and 75°.

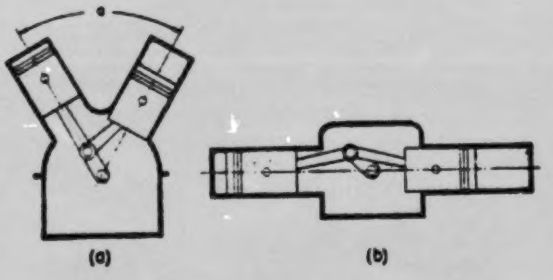


Figure 1.3. V-Type Engines.

(3) Flat engine. As illustrated in figure 1.3(b), V-type engines having 180° between the banks are called flat engines. This arrangement is used mostly for trucks and buses.

(4) Multiple-engine units. To increase the engine power without increasing its bore and stroke, two and four complete engines, having six or eight cylinders each, are combined in one unit by connecting each engine to the main drive shaft "5," as shown in figure 1.4(a) and (b), by means of clutches and gears or clutches and roller chains. Figure 1.4(a) shows a twin-engine; figure 1.4(b), a quadruple-engine or quad.

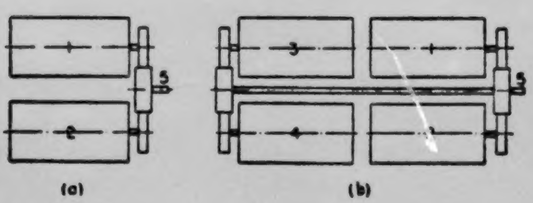


Figure 1.4. Multiple-Unit Engines.

(5) Vertical-shaft engine. A recent development is an engine with four connecting rods attached to one crankpin, as shown in figure 1.5. The four cylinders are all in the same plane, the crankshaft thus being vertical. Four banks, located one on top of the other and using one crankshaft with four cranks, form a compact 16-cylinder engine used in the Navy under the name of the Pancake engine.

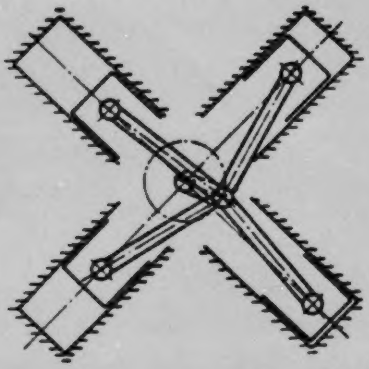


Figure 1.5. Top View of a Pancake Engine.

c. Piston action. Diesel engines can also be classified by their piston action as explained in subparagraphs (1) through (3).

(1) Single-acting engines use only one end of the cylinder and one face of the piston to develop power. The engines in figures 1.1 through 1.5 are all single-acting.

(2) Double-acting engines use both ends of the cylinder and both faces of the piston to develop power. Double-acting engines are built only in large and comparatively low-speed units.

(3) Opposed-piston engines have two pistons per cylinder, driving two crankshafts. The design presents many advantages from the viewpoint of combustion of the fuel, engine maintenance, and accessibility of all parts, except the lower crankshaft.

d. Fuel injection. Diesel engines are divided into air injection and solid or mechanical-injection engines. Chapter 4 discusses the meaning of these terms and the differences between the two types.

e. Speed. All diesel engines can be divided into three classes: low-speed, medium-speed, and high-speed engines. The present trend is away from low- and even medium-speed engines toward increasingly higher-speed engines.

1.11. SUMMARY

The marine diesel engine, regardless of its outward configuration, has only a few main basic internal parts. They are the cylinder, piston, connecting rod, crankshaft, camshaft, crankcase, and fuel injection system. Although various auxiliary parts are needed, the few basic parts remain the same from engine to engine.

Since diesel engines come in many different types, there is a need for a classification system. This is accomplished by five categories: operating cycle, cylinder arrangement, piston action, method of fuel injection, and speed.

Section II. Principles

1.12. GENERAL

As section I explains, a diesel engine operates on one of two cycles, either the four-stroke-cycle or the two-stroke-cycle. The steps in the four-stroke-cycle are intake, compression, ignition, and exhaust. The steps in the two-stroke cycle are exhaust and intake, and compression and ignition. This section covers functions which supplement the steps of the four-stroke and two-stroke engine. They are scavenging, turbulence, supercharging, and timing.

1.13. FOUR-STROKE-CYCLE EVENTS

A round of events recurring regularly and in the same sequence is known as a cycle. The cyclic events in a four-stroke diesel engine are, in sequence, (1) filling of the engine cylinder with fresh air; (2) compression of the air charge to raise its pressure and temperature to that necessary to ignite and burn the fuel efficiently; (3) combustion of the fuel and expansion of the hot gases; and (4) emptying the cylinder of the burned gases by exhausting them. When these four events are completed, the cycle is repeated. When each of these events takes place, roughly speaking, during one stroke of the piston, the cycle is called a four-stroke cycle.

The positions of the piston when it is nearest to the cylinder head and farthest away from it are called top and bottom dead center, or for short, top and bottom center, indicated by "t. c." and "b. c." The reason for this designation is that at these positions the connecting-rod centerline coincides with the crankthrow centerline and the piston cannot be moved by gas pressure acting upon its surface. The motive force must come from the rotating crank acting through the connecting rod.

The four main events are shown diagrammatically in figure 1.6. During the first or suction stroke, figure 1.6(a), the piston (P) moves downward, pulled by the connecting rod (r), the lower end of which is moved by the crank (C). The piston motion creates a vacuum in the cylinder, and outside air is drawn or sucked into the cylinder through the intake valve (i) which opens at about the beginning of the suction stroke and stays open until the piston reaches the lower or bottom center (b. c.).

When the piston has passed b. c., the second or compression stroke begins, figure 1.6(b); the intake valve is closed and the upward motion of the piston pushed by the crank and the connecting rod begins to compress the air charge in the cylinder.

Shortly before the piston reaches top center (t. c.), liquid fuel in a finely atomized spray is admitted into the cylinder containing hot compressed air. The fuel is ignited by the heat of the air compressed in the cylinder and burns during the first part of the downward piston stroke. During this downward or third stroke, called working or power stroke, figure 1.6c, the hot gases, whose

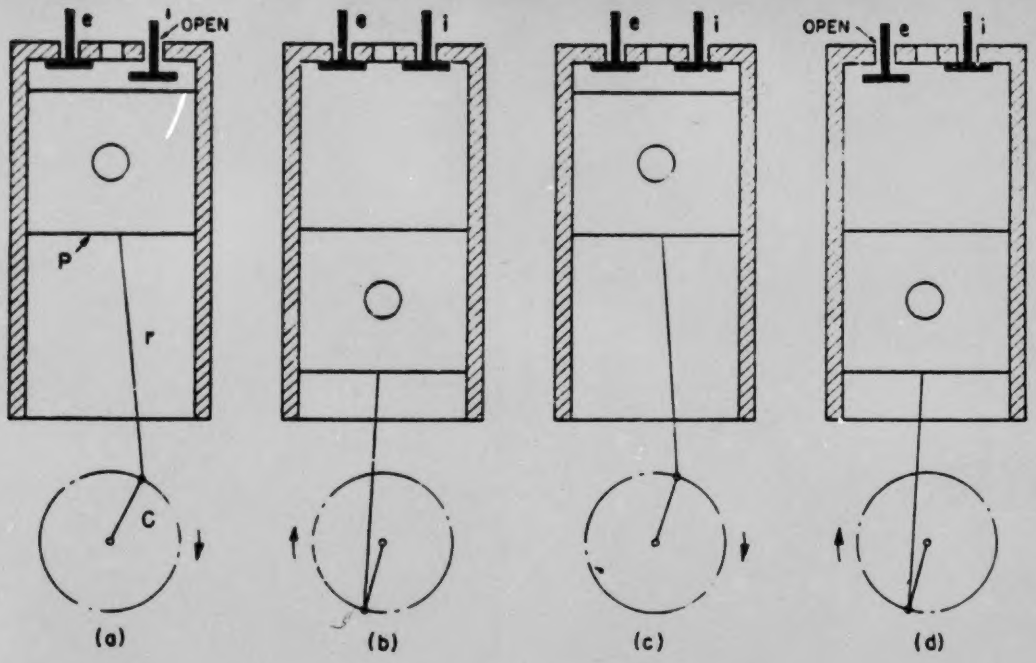


Figure 1.6. Four-Stroke-Cycle Events.

pressure was considerably increased by the combustion of the fuel charge, force the piston downward and expand because of the increasing cylinder volume.

Shortly before the piston reaches the bottom center, the exhaust valve (e) opens, figure 1.6d, and the hot products of the combustion, having a relatively high pressure in spite of the previous expansion, begin to rush out through the exhaust ports into the outside atmosphere. During the following fourth or exhaust stroke, the piston moves upward, pushed by the crank and connecting rod, expelling the remaining products of combustion, until near top center the exhaust valve is closed, the intake valve is opened, and the whole cycle starts again. As can be seen, the four strokes require two engine revolutions. Thus in a four-stroke-cycle engine, one power stroke is obtained for every two engine revolutions, or the number of power impulses per minute are equal to one-half of the rpm of the engine.

Actually, the dividing points between the four main events do not come at the very beginning and end of the corresponding strokes. The differences are smaller in low-speed engines and increase as the engine speed increases. The intake valve is opened before top center, 10 to 25 crank-angle degrees; it is closed from 25 to 45 crank-angle degrees after bottom center. The fuel injection starts some 7° to 26° before t. c. To release the exhaust gases in proper time, the exhaust valve begins to open 30° to 60° before b. c. and close 10° to 20° after t. c.

1. 14. COMPRESSION

The air charge is compressed during the second or compression stroke for two reasons. The first is to increase the thermal or overall efficiency of the engine by increasing the final temperature of combustion; this applies to all internal combustion engines, both of the spark-ignition as well as the so-called diesel type. The second reason is to raise the temperature of the air charge so much that, when the finely atomized fuel is injected into the hot air, the fuel will ignite and begin to burn without any outside source of ignition such as the spark plug used in automobile engines.

Compression ratio of an internal combustion engine is the ratio of the volume V_1, cu. in., of the gases in the cylinder with the piston at bottom center to the volume V_2 of the same gases with the piston at top center. Compression ratio is designated by r. Compression ratio equals volume at bottom center divided by volume at top center or:

$$r = V_1 \div V_2$$

The volume V_2 is called the compression or combustion space. The volume V_1 is equal to the sum of the piston displacement of one cylinder plus the combustion space.

Diesel engines use compression ratios of 12:1 to 19:1. Theoretically, an increase of the compression ratio raises the thermal efficiency of the engine and lowers its fuel consumption. However, an increase of the compression ratio is accompanied by higher gas pressures and combustion temperatures. This causes increased stresses and pressures in various engine parts, and to counteract these ill effects requires stronger, heavier parts and increases unduly the weight of an engine. Higher temperatures and pressures also increase the wear and tear of an engine and thus decrease its reliability.

1. 15. COMBUSTION

Two distinctly different methods of burning the fuel in an engine cylinder exist: at a constant volume and at a constant pressure. Combustion at constant volume means that during combustion the volume does not change and that all the heat energy developed by the fuel goes into an increase of the gas temperature and pressure. Combustion at constant volume also means that combustion proceeds at such a high rate that the piston has practically no time to move during combustion. Such a combustion is obtained when the piston is passing top center. The advantage of this method of fuel combustion is a high thermal efficiency. Its disadvantage is a very sudden pressure increase and resulting noisiness of the engine. Such combustion is somewhat approached by spark-ignited gasoline engines.

Combustion at constant pressure means that during combustion the temperature increases at such a rate that the resulting increase of pressure is just enough to counteract the influence of the increasing volume and the pressure does not change. The heat energy developed by the fuel goes partly into an increase of the gas temperature and partly into performing outside work. In the case of an engine with constant-pressure combustion, the fuel is burned gradually so that the pressure attained at the end of the compression stroke is maintained during the greater part of the combustion event. Such a combustion was used in the original low-speed, air-injection diesel engine. Its advantage is a smoothly running engine producing a more even torque because of the extended combustion pressure. However, it is not suitable for high-speed oil engines.

High-speed diesel engines of the present operate on a cycle which is approximately a combination of the above two methods; part of the fuel is burned rapidly, almost at a constant volume near the top dead center, and the rest is burned while the piston begins to move away from top center. However, the pressure does not remain constant, but usually increases and then decreases. In general this cycle resembles more the constant-volume combustion cycle than the cycle of the original diesel engines. Its advantage is high efficiency, with low fuel consumption. Its drawback is in the difficulty of preventing rough and noisy operation of the engine.

1.16. TWO-STROKE-CYCLE EVENTS

A two-stroke cycle is completed in two strokes, or one revolution of the crankshaft, whereas a four-stroke cycle requires two revolutions. The difference between the two-stroke and four-stroke engine is in the method of removing the burned gases and filling the cylinder with a fresh charge of air. In a four-stroke engine, these operations are performed by the engine piston during the exhaust and intake strokes. In a two-stroke engine, they are performed near the bottom dead center by means of a separate air pump or blower.

The compression, combustion, and expansion events do not differ from those of a four-stroke engine. The filling of the cylinder, called scavenging, with a fresh charge may be explained as follows: when the piston has traveled 80 to 85 percent of its expansion stroke, exhaust valves e, e, as shown in figure 1.7, are opened, and the exhaust gases are released and begin to escape from the cylinder. The piston continues to move toward the bottom center and soon uncovers ports s, s, through which lightly compressed air begins to enter the cylinder. The air, having a slightly higher pressure than the hot gases in the cylinder, pumps out the hot gases through valves e, e, figure 1.7(b). This operation is called scavenging. The air admitted is called scavenge air; the air admittance ports, scavenge ports. About the time when the piston, on its upward stroke, closes ports s, s, the exhaust valves e, e, are also closed, figure 1.7(c), and the compression stroke begins.

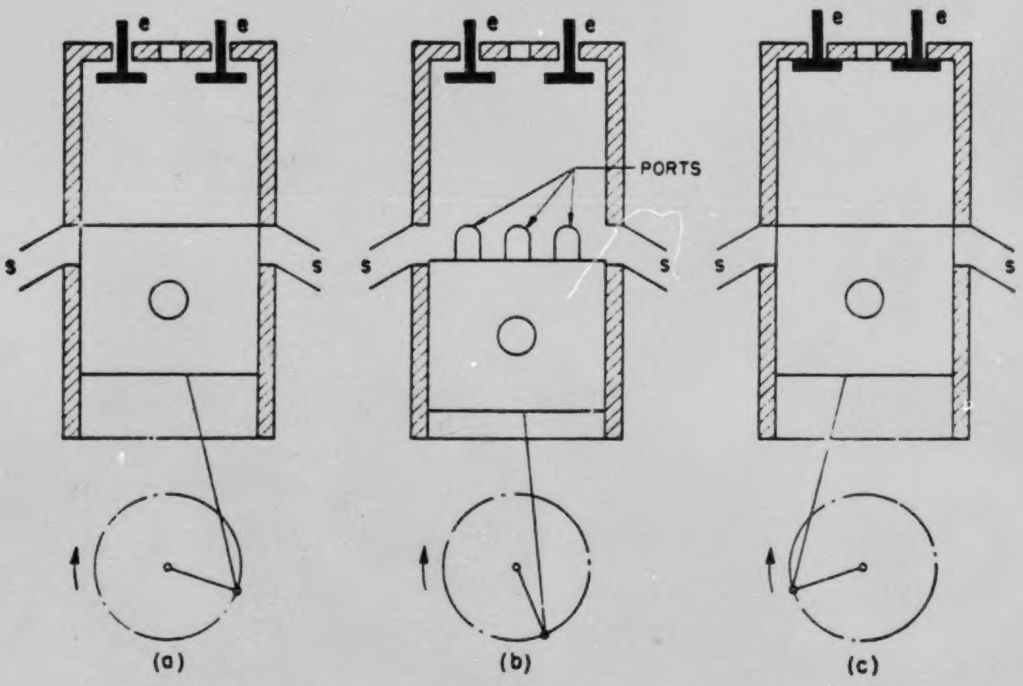


Figure 1.7. Scavenging of a Two-Stroke Engine.

The advantage of the two-stroke engine is the elimination of one scavenging and one charging stroke required in a four-stroke-cycle operation. Thus, the cylinder delivers one power stroke for every revolution of the engine as compared with one power stroke for every two revolutions in a four-stroke-cycle engine. Theoretically, if all other conditions such as bore, stroke, speed, and gas pressures are equal, a two-stroke-cycle engine should develop twice the power of a four-stroke-cycle engine. This means also that a two-stroke engine would weigh only one-half as much as a four-stroke engine of the same power and should produce a more even torque. Practical factors prevent the attainment of these ideal figures.

The advantages are important in ship installations, and, therefore, two-stroke engines are used in vessels much more than four-stroke engines, particularly in larger power units. The disadvantage of the two-stroke operation is the higher working temperature of the piston and cylinder head because of combustion occurring every revolution and resulting in distortion of these and related parts.

1.17. SCAVENGING METHODS

Figure 1.7 illustrates only one of several methods of cylinder scavenging. In some engines the exhaust gases are let out through ports, uncovered by the piston, the same as the scavenge ports (s, s) in figure 1.7. Depending upon the location of the exhaust ports to that of the scavenge ports, there exist two basically different methods of scavenging: direct or cross-flow scavenging and loop or return-flow scavenging, as shown in figures 1.8 and 1.9.

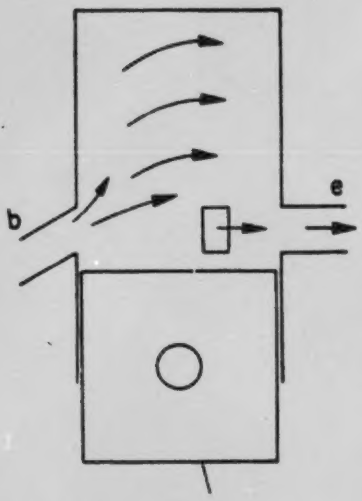


Figure 1.8. Direct or Cross-Flow Scavenging.

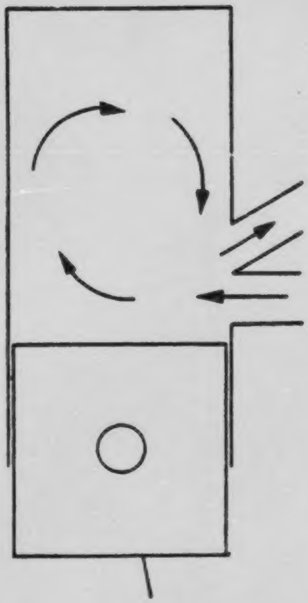


Figure 1.9. Return-Flow or Loop Scavenging.

In cross-flow scavenging, the piston uncovers first the exhaust ports (e, e) and releases the pressure; going down further, the piston uncovers the scavenge port (b, b) and begins to admit slightly compressed air whose stream is directed mainly upward, as indicated by the arrows, and thus pushes out the exhaust gases through port (e, e). Having passed the dead center, the piston closes first the scavenge ports and, soon afterward, the exhaust ports. The fact that the exhaust ports are closed after the scavenge ports permit some of the air charge to escape from the cylinder. This is a disadvantage of this scavenge scheme. However, it has also the decided advantage of simplicity of construction and of maintenance because of the absence of valves which must be kept tight.

Return-flow or loop-scavenging is similar to cross-flow scavenging in the sequence of the port opening. However, the direction of air flow is different, as indicated by the arrows. Its advantage is that the bulky scavenge-air and exhaust-gas ports are located on one side of the cylinder, thus giving better accessibility. This scheme is particularly suitable for double-acting engines, since with them the operation of the exhaust valves for the lower combustion space becomes complicated. When used for double-acting engines, the scheme is improved by the introduction of rotary exhaust valves. As can be seen in figure 1.10, during the release of the exhaust gases, valve (r) is open but it is being closed when the piston on the return stroke covers the scavenge ports. By this arrangement, the escape of air charge is eliminated during the beginning of the compression stroke when the exhaust ports are not yet covered. Some time after the exhaust ports are covered by the piston, the rotary valve is opened, getting it ready for the next cycle. As can be seen from figure 1.10, the length of the piston is exactly equal to the length of the stroke to control the exhaust and scavenge events alternately by the upper and lower edges of the piston.

The oppposted-piston scheme is shown in figure 1.11. The lower piston controls the exhaust ports; the upper one, the scavenge ports. To obtain the necessary preliminary release of the exhaust gases, or an uncovering of the

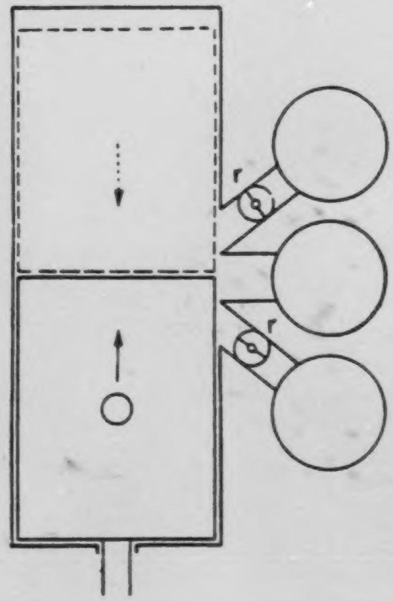


Figure 1.10. Return Scavenging in a Double-Acting Engine.

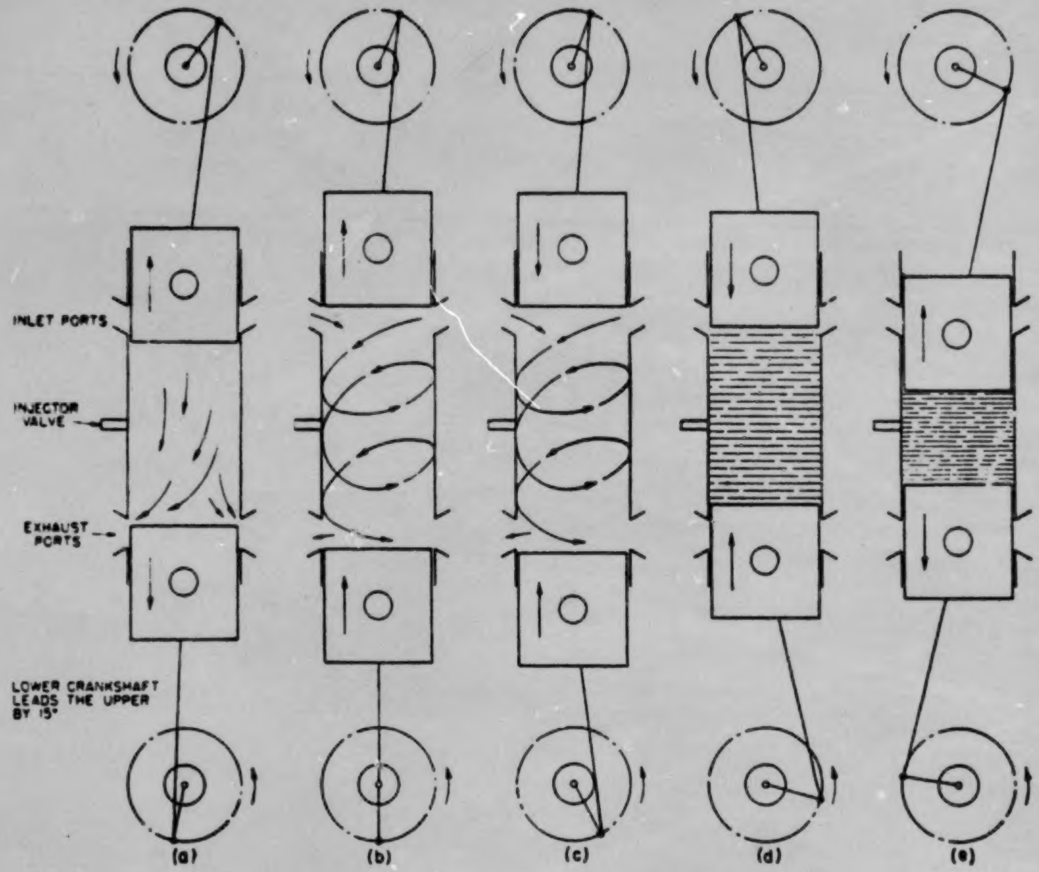


Figure 1.11. Opposed-Piston Engine Operation.

exhaust ports ahead of the scavenge ports, the crank of the lower crankshaft is advanced in respect to the crank of the upper crankshaft, or leads the upper crank by some 10° to 15°. In this way, the exhaust ports are opened first, figure 1.11(a); when the pressure is sufficiently lowered, the scavenge ports are uncovered, figure 1.11(b), and scavenging begins to take place. After the exhaust ports are closed, additional admission of air takes place, figure 1.11(c), until the scavenge ports are also covered and compression of the air charge takes place, figure 1.11(d). Slightly before the pistons reach the point at which they are closest together, fuel is injected, ignited, and burns while the expansion stroke starts, figure 1.11(e). The power delivered by the upper pistons to the upper crankshaft is transmitted to the lower main crankshaft by an intermediate vertical shaft and two pairs of bevel gears. The advantages of this scheme are:

a. Efficient scavenging of the cylinder and hence greater power is developed.

b. Absence of valves and valve-operating gears.

c. Absence of cylinder heads which are complicated castings and a source of trouble in engine operation.

d. Good accessibility for the inspection and repair of most parts, except of the lower crankshaft.

The two scavenge schemes, shown in figures 1.7 and 1.11, are also classified as uniflow scavenging. In both cases the exhaust gases and scavenging air are flowing in the same direction with less chance for formation of turbulences which are unavoidable with cross- and return-flow scavenging.

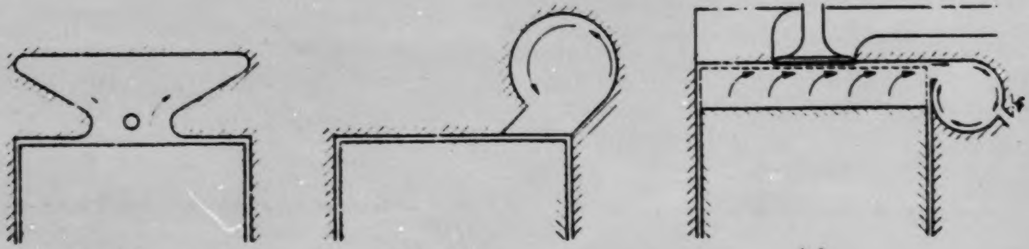
1.18. TURBULENCE

To obtain efficient, smokeless combustion, the fuel injected into the cylinder must be broken up in very fine particles, be well atomized, and the fuel particles must be distributed uniformly through the whole combustion space. In air-injection engines, the distribution of the fuel is accomplished through a thorough mixing of the injection air, carrying the atomized fuel, with the air in the cylinder. In mechanical- or solid-injection engines, distribution is accomplished by using nozzle tips with several holes and by directing the fuel sprays so as to reach the desired portions of the combustion space or by using pintle-type nozzles with a cone-shaped spray. In larger engines, better fuel distribution is obtained by using two or more separate fuel nozzles, each having several holes or fan-shaped sprays. However, distribution of the fuel by separate sprays usually is not sufficient. Distribution of the fuel in the air charge is improved by stirring up the air in the combustion space and by creating air turbulences, and thus mixing air having too much fuel with air which does not have any fuel.

While theoretically one pound of air is sufficient to burn completely 0.065 pound of fuel oil, actually not all of the oxygen of the air will be reached by the fuel particles. Hence, only a smaller amount of fuel, on the average not over 0.052 or even 0.043 pound, can be burned efficiently with 1 pound of air in the combustion chamber.

Turbulences in the air charge help to reduce the amount of air not reached by the fuel particles, and thus increase the power output of the engine.

Turbulences may be created by various means, including special shapes of the piston crown or of the entire combustion chamber. Figure 1.12 shows examples of different turbulent heads. In figure 1.12(a) turbulences are created by a restriction through which the air has to pass when the piston moves upward; the air velocity at the restriction is several times higher than before and after it, and the change of velocity creates a turbulent flow into which the fuel is injected from the fuel nozzle. Figure 1.12(b) shows a Ricardo-Comet head used in Waukesha diesel engines; here turbulences are created not only by the restriction, but also by forcing the air to travel on a circular path. Figure 1.12(c) shows a turbulent head used in Hercules diesel engines, which is similar to the Ricardo head. However, it has an additional feature: when the piston approaches the dead center, it begins to cover partially the air passage between the cylinder and the turbulence chamber. This increases the air velocity in the passage, and thus makes more turbulent the flow of air into which the fuel is injected from nozzle (f).



(a) (b) (c)

Figure 1.12. Turbulent Heads.

Turbulence in two-stroke engines is created by making the scavenge-air ports tangential, as shown in figure 1.13. It is noteworthy that a circular movement of the air created during scavenging continues up to the time of fuel injection, in spite of the fact that the air has been displaced from one end of the cylinder to the other and compressed to a small fraction of its original volume.

Another method of creating turbulence is used in the so-called Lanova energy cell, shown in figure 1.14. The fuel is injected from the nozzle, ignites, and burns in the main combustion chamber, while the rest is injected in a more or less solid stream in the so-called energy cell or minor air cell. Here it is atomized or broken

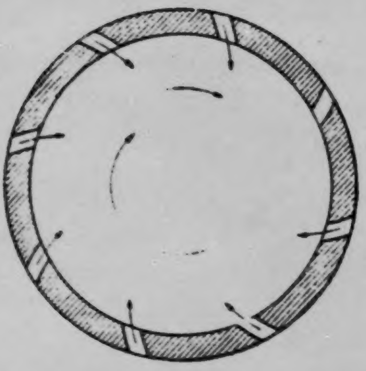


Figure 1.13. Turbulence in a Two-Stroke En-Engine.

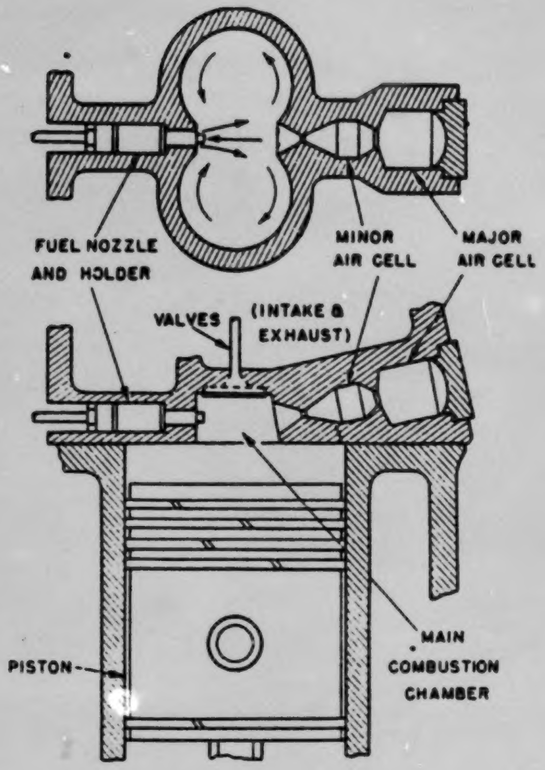


Figure 1.14. Lanova Combustion Chamber With Energy Cell.

up in a fine mist and ignited; the resulting combustion raises the pressure in the minor air cell over the pressure in the main combustion chamber and throws the burned and unburned fuel back into the main chamber, creating a strong turbulence (indicated by arrows) and helping to burn the rest of the unburned fuel.

1.19. SUPERCHARGING

Supercharging has as its object an increase in the power which an engine of given piston displacement and speed can develop. Since in a diesel engine the power is developed by the burning of fuel, an increase of power requires more fuel to be burned, and, therefore, more air must be available since each pound of fuel requires a certain amount of air. All conditions being the same, a given volume will hold a greater weight of any gas, including air, if the gas pressure is increased. Thus, supercharging means a higher pressure of the air charge in the cylinder at the beginning of the compression stroke.

To increase the air pressure in four-stroke engines, the air charge is not sucked into the cylinder, or, as it is called, is not admitted by natural aspiration by the receding piston, but is pushed in by a higher pressure created by a separate air pump or blower The three types of blowers used are reciprocating piston pumps, similar to an air compressor; rotating positive-displacement blowers, the Root-blower type; and centrifugal high speed blowers, similar to centrifugal pumps.

When a supercharger is applied to a four-stroke engine, the main change required in the engine design is in timing of the intake and exhaust valves. The intake-valve opening time is advanced and the exhaust-valve closing is retarded. The two valves are designed to stay open simultaneously for about 80 to 160 degrees, the selection depending upon the normal engine speed. This simultaneous opening is called overlapping. Tests have shown that an overlap of 40° to 50° increases the power output of an engine about 5 percent if the supercharging is very small, sufficient only to eliminate the vacuum in the cylinder during the intake stroke, and up to 8 percent with a supercharger pressure of 12-inches mercury, as compared with an overlap of 10° to 20° commonly used in unsupercharged engines. The total power gain because of supercharging varies from 20 to 50 percent, depending upon the supercharging pressure.

It should be noted that simultaneously with an increase of the mean effective pressure supercharging also increases the maximum or firing pressures and the maximum temperatures. On the other hand, the fuel consumption per hp-hr usually decreases with supercharging because of an increase of turbulence and hence better mixing of the fuel with the air charge.

Two-stroke engines usually have a blower to obtain scavenge air and their supercharging is obtained simply by increasing the amount and pressure of scavenge air. In addition, a slight change of the exhaust and scavenge timing is made to retain more scavenge air at the beginning of the compression stroke.

1.20. COMBUSTION AND IGNITION DELAY

Regardless of how finely atomized the fuel injected into the combustion space of the cylinder filled with air is, it takes some time before the relatively cold fuel spray becomes heated and vaporized so as to ignite and to continue burning. This time element is rather small when expressed as a fraction of a second but quite appreciable when expressed as the number of degrees which the crank travels between the time when the fuel is introduced into the cylinder and when the first particles of it are ignited. This time element is called ignition delay or ignition lag and amounts to several degrees of crank travel.

After ignition has started, the fuel will continue to burn within the engine cylinder. This combustion usually is accompanied by a rather quick pressure rise. In the meantime, the pump continues to deliver fuel, and during the third period of combustion, the fuel burns more or less as it is introduced. However, since the supply of oxygen in the air charge gradually is being used up by the combustion, the fuel particles introduced toward the end of the injection have more difficulty meeting the necessary particles of oxygen. Compression is consequently retarded and when injection is terminated some unburned fuel is still present in the cylinder and continues to burn. The piston by this time has moved away from top dead center and its speed increases; therefore, the pressure begins to fall in spite of additional heat being developed by the rest of the fuel.

The highest thermal efficiency is obtained from the fuel which burns at the highest compression ratio, at top center. In practice, burning of the fuel must start before top dead center and be completed after top dead center. The shorter the period of combustion, the higher the thermal efficiency, and the lower the fuel consumption. However, an excessively short burning period requires a fast pressure rise and produces high maximum pressures. The result is undesirable because of the noise of engine operation and high pressures and stresses in various engine parts.

1.21. INJECTION TIMING

As paragraph 1.20 explains, there is a certain lag between the time that the fuel is injected into the cylinder and the time that it ignites and continues to burn, raising the cylinder pressure. This time lag, called ignition delay, requires an advance of the fuel injection several crank-angle degrees before top dead center. In addition, it should be noted that there exists another lag in the fuel injection. The beginning of the delivery stroke of the injection pump is set to correspond to a certain position of the engine crankshaft. The injection timing is checked by slowly turning the engine over. The actual admission of the fuel into the engine will start several crank-angle degrees later. The reason for this time lag is the mechanical flexibility of the injection mechanism, taking up of clearances between the various rollers, pins, levers, etc., and the compressibility of the fuel oil, especially noticeable with a long fuel line. This lag is called injection lag and amounts to several crank-angle degrees.

Both the ignition and injection lags depend upon a number of factors that may vary considerably from engine to engine. The following data obtained from actual tests may serve as an illustration. In an engine operating at 900 rpm, the injection was set to begin at

22° before top dead center; actual injection started only about 17° before top dead center, which gives an injection lag of 5°; ignition started 8° before top dead center, which gives an ignition delay of 9°, or a total lag of 14° behind nominal fuel timing. On the other hand, the pump delivery stroke was cut off 3° before top dead center, but because of the expansion of the fuel compressed in the fuel line, the actual end of injection occurred slightly after top dead center. In other engines the lag may be greater or smaller.

The only way to determine the correct fuel timing is by operating the engine, changing the timing, and finding the timing with which the engine operates best; i.e., has the lowest fuel consumption, carries the highest load without smoking, and runs the smoothest. Such timing is worked out at the engine factory and is given in the appropriate technical manual.

1.22. VALVE TIMING

As paragraph 1.13 explains, the opening of both the exhaust and intake valves occurs before the corresponding dead center, and their closing after it. The causes are partly in the mechanical lag of action, because of clearances which must be taken up and the flexibility of the long push rods, rockers, etc., but chiefly in the necessity of a gradual opening and closing of the valves. Thus, an appreciable time element elapses between when the valve begins to leave the seat and when it has sufficiently moved away from the seat to allow exhaust gases to pass from the cylinder, in the case of an exhaust valve, and air into the cylinder, in the case of an intake valve. The same holds true for the closing of the valves, but in reserve: several crank-angle degrees before a valve touches its seat, the passage becomes so restricted that the flow of gases practically stops. The gradual opening and closing are necessary to overcome the forces of inertia of the parts of the valve actuating mechanism without exerting undue pressure between the cams, cam followers, and various pins and bearings during the opening of a valve and the pounding of the valve against its seat when it is being closed.

The best timing depends upon a number of factors such as valve lift, shape of the cam, speed of the engine, and restrictions in the cylinder head passages. The proper timing is found and set when the engine is tested at the factory and is given in the manufacturer's instruction book. It should be checked and maintained by the operator. Even a slight change of the clearance between the cam and the cam followers, which can occur when a valve is ground or when the valve actuating mechanism is disassembled and put together without careful checking, will affect the timing. An increase of the clearance will retard the opening of a valve and advance its closing; a decrease of the clearance will cause the opposite to happen. An excessive decrease of the clearance may prevent the valve from seating properly and result in the related consequences, such as loss of power and burning of the valve seat.

The same remarks apply to the timing of the exhaust valves of two-stroke engines.

1.23. SUMMARY

The operation of a diesel involves the admission of fuel and air into a combustion space and the compression and ignition of the charge. The four-stroke engine accomplishes this in four steps with two revolutions of the crankshaft. The first step is the drawing of air into the cylinder by the downward stroke of the piston. The second step is the compression of the air charge on the piston's upward stroke; ignition on the downward stroke completes the third step. The fourth step is the expelling of exhaust on the piston's next upward stroke.

The two-stroke accomplishes this in one crankshaft turn and two steps. The first step begins with the cylinder at bottom center where air is blown into the cylinder which expells the exhaust and builds an air charge and the piston moves upward compressing the charge. The second step begins at top center where the ignition occurs forcing the piston back down for another cycle.

These cycles are supplemented by such operations as supercharging, turbulence, valve timing, ignition timing, and injection timing.

Supercharging increases the efficiency of an engine by forcing more air into the cylinder than could be gained by natural aspiration. This is accomplished by using one of the three types of blowers available. They are the reciprocating piston pump, rotating positive-displacement blower, and centrifugal high speed blower. To use this large air charge effectively it must be thoroughly mixed with the fuel spray. This is done by creating a turbulence within the cylinder. Turbulence may be created by various means, including special shapes of the piston crown or of the entire combustion chamber.

Regardless of how finely atomized the fuel injected into the combustion space of the cylinder filled with air is, it takes some time before the relatively cold fuel spray becomes heated and vaporized so as to ignite and to continue burning. This is called ignition delay and amounts to several degrees of crank travel. There is also a lag in the injection of fuel into the cylinder caused by mechanical flexibility of the injection mechanism and compressibility of the fuel in long fuel lines. This also amounts to several crank-angle degrees. The opening of both the exhaust and intake valves occurs before the corresponding dead center, and their closing after it. The causes are partly in the mechanical lag of action because of clearances which must be taken up and the flexibility of long push rods, rockers, etc., but chiefly in the necessity of a gradual opening and closing of the valves.

Chapter 2

STRUCTURAL ENGINE PARTS

2.1. INTRODUCTION

The main parts of an engine, excluding accessories and systems, may be divided into two principal groups. One group includes those parts which, with respect to engine operation, do not involve motion; namely, the structural frame and its components and related parts. The other group includes those parts which involve motion. Section I includes such stationary parts as engine frame, crankcase, cylinder, cylinder liner, cylinder head, and crankshaft bearings. Section II covers the moving parts which are the crankshaft, piston, piston rings, piston pins, piston rods, and connecting rods.

Section I. Main Stationary Parts

2.2. GENERAL

The main purpose of the stationary parts of an engine is to maintain the moving parts in their proper relative position so that the gas pressure produced by combustion can fulfill its function, which is pushing pistons and rotating the crankshaft. The prime requirements for the stationary parts of marine engines are ample strength, low weight, minimum size, and simplicity of design. Strength is necessary if the parts are to withstand the extreme forces developed in an engine; space limitations aboard ship make minimum weight and size essential; while simplicity of design is of great importance when maintenance and overhaul are involved.

2.3. ENGINE FRAME

The frame connects the top of the cylinder to the supports for the crankshaft. In the earlier designs, at present used only in large, low-speed engines, the frame consists of a separate cylinder block, crankcase, and bed plate with an oil pan or sump, as illustrated in figure 2.1. The main bearings supporting the crankshaft were held in the crankcase, while the pistons operated in the cylinder block above it. The gas-pressure load was taken up by tie bolts running from top to bottom. Cylinder block, crankcase, and bed plate were made of gray-iron castings.

Modern designs of high-power output engines have frames welded of steel with plates located at places where the loads occur, as shown in figure 2.2. The customary arrangement combines the cylinder block and oil pan with the main bearing supports, although a separate crankcase section is sometimes used. Cylinder blocks and crankcases of small high-speed engines are still made of cast iron.

The crankcase is often integral with the cylinder block. In the models where it is a separate section, it generally consists of a plain rectangular frame with cross-ribbing to provide rigidity. Occasionally, the main bearings are held by a cross-ribbing in the crankcase, but more often they are hung from the bottom of the cylinder block. Some engines have access doors or plates to permit repair and/or observation of the bearings.

2.4. CYLINDERS

The cylinders were separate units on some older models, but in modern engines they are secured within the block which also contains passages for cooling water,

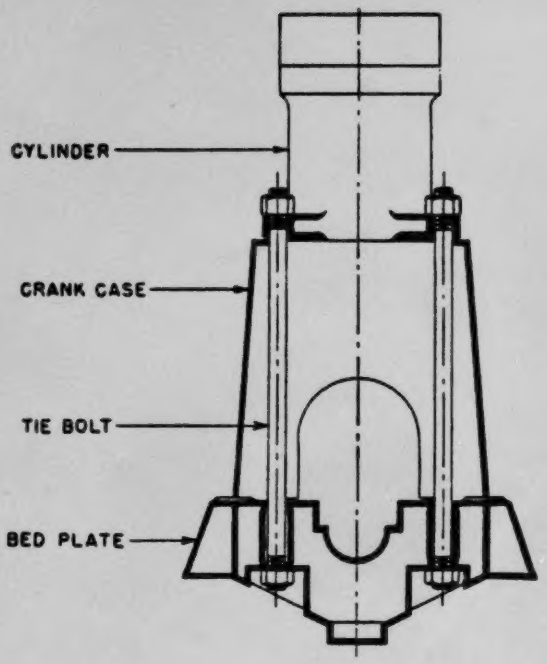

CYLINDER
CRANK CASE
TIE BOLT
BED PLATE

Figure 2.1. Engine Frame With Tie Bolts.

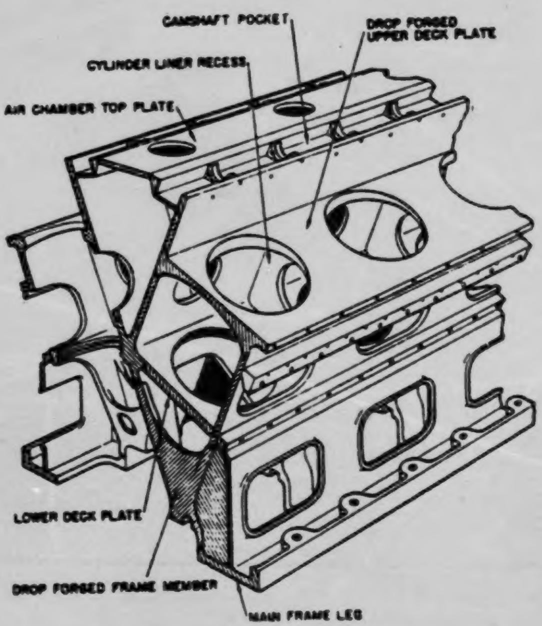

CAMSHAFT POCKET
DROP FORGED UPPER DECK PLATE
CYLINDER LINER RECESS
AIR CHAMBER TOP PLATE
LOWER DECK PLATE
DROP FORGED FRAME MEMBER
MAIN FRAME LEG

Figure 2.2. Sectional Sketch of Winton Welded Frame.

lubricating oil to the bearings, and intake air. Each cylinder is secured in a separate compartment with cross-bracing between the compartments.

Subparagraphs a through c describe the three types of cylinder liners in use.

a. Dry liners are simple sleeves with thin walls inserted in the cylinders as part of the cylinder block, shown in figure 2.3. The cooling water moves about the outer cylinder and does not contact the liner. The liner is inserted in the cylinder with a light press fit. When worn or scored it can easily be removed and replaced by a new liner.

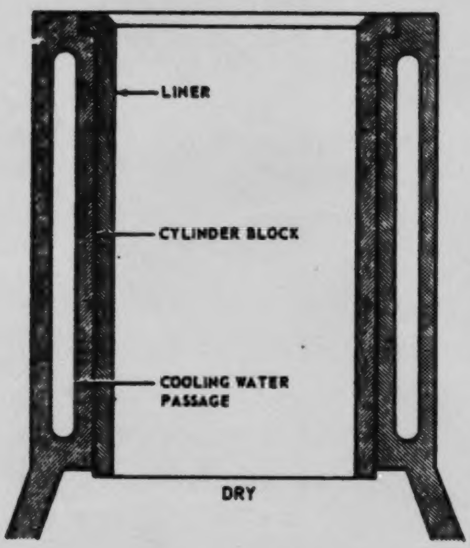


Figure 2.3. Dry Liner.

b. Wet liners are sleeves whose outer surface comes into direct contact with the cooling water, illustrated in figure 2.4. The liners are normally sealed against water leakage at the top end by a gasket under the flange or a machined fit, and by rubber or neoprene rings around lengthwise. The thickness of the wall is such as to take the full working pressure of the gases.

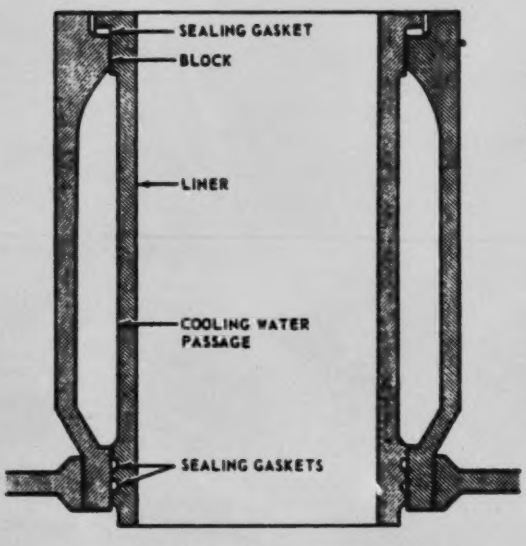


Figure 2.4. Wet Liner.

c. Water jacketed liners have their own cast-on or permanently shrunk-on jacket around the outside for the circulating cooling water, as shown in figure 2.5. The water is admitted into the bottom of the jacket and leaves through the top. This type is used mostly in two-stroke engines where it is difficult to obtain a water-tight seal around the parts when using a wet liner, because of the expansion of the liner by heat during engine operations.

The cylinder liner must be made of material which will enable the piston and rings to move up and down with the minimum friction, and will give the least wear to both the liner and the piston parts. Cast iron is the usual material, although steel sleeves are sometimes used. A recent development in the manufacturing of cylinder liners has been to coat the inside of the liner with a 0.003- to 0.006-inch layer of electro-deposited porous chormium. The chromium resists wear, while the pores in the plating hold lubricating oil and maintain a lubrication film necessary to reduce friction and scuffing.

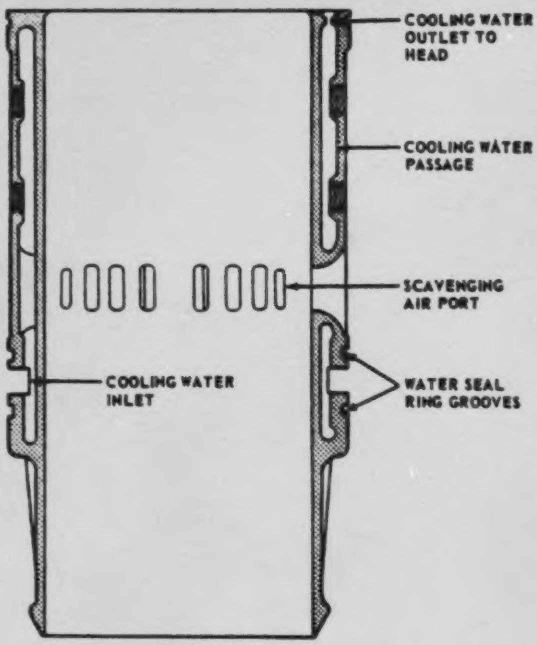


Figure 2.5. Water-Jacketed Liner.

The cylinder head seals the combustion chamber, and in most engines, contains the valves and passages for intake and exhaust gases, the fuel injection nozzle, the air starting and relief valves, and passages for the cooling water from the cylinder jacket, as shown in figure 2.5. It is a casting of alloy iron, seldom of aluminum. Because of the heat passing through it from the combustion chamber and the exhaust passages, it has to be water-cooled. Such cooling prevents excessive temperatures which might crack it and which would interfere with the operation of the fuel injection nozzle and all other valves. The larger-bore engines have individual heads for each cylinder, while small-bore engines may have a single head covering all cylinders, or pairs of cylinders.

2.5. CRANKSHAFT BEARINGS AND CROSSHEAD GUIDE

In older designs and in very large, low-speed diesel engines, the main and crankpin bearings consist of heavy, cast-iron or cast-steel boxes with a thick, up to 1/2-inch, babbit lining. Babbit is a soft alloy tin, copper, and antimony used to line bearing shells. Each bearing must be hand-scraped to a running fit with its journal. All modern diesel engines, regardless of size and speed, have precision bearings. They are separate from the saddles and connecting rods. They consist of relatively thin steel, bronze, or brass shells, with a lining of bearing metal, which is generally 1/32-inch or less in thickness. The bearing metal may be one of several types which prove satisfactory: lead-base babbit, copper-lead, and cadmium silver.

Only double-acting diesel engines require a cross head and crosshead guide; however, a few of the largest single-acting engines also use them. The purpose of the crosshead guide is to take the side thrust coming from the angularity of the connecting rod, as illustrated in figure 2.6, which otherwise would be taken by the cylinder liner. The bearing surface of the crosshead guide is a flat slipper. Bearing loads are low and with proper lubrication ordinary babbit usually suffices as a bearing surface.

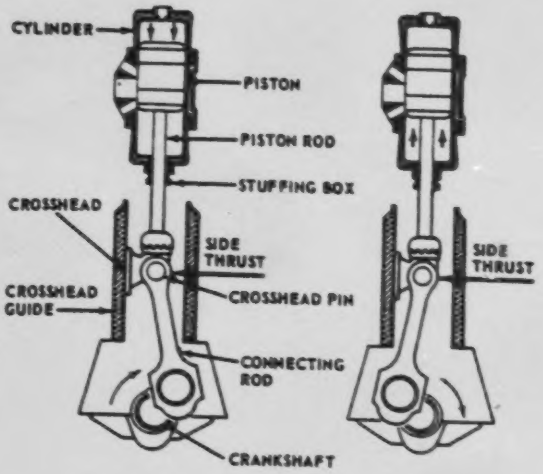


Figure 2.6. Crosshead Piston Side Thrust.

2.6. SUMMARY

The engine block determines the outward appearance of the engine and supports the cylinders, cylinder liners, and cylinder heads. For larger engines the frame consists of a separate cylinder block, crankcase, and bed plate; the smaller high-speed engines have a cast-iron block.

The cylinder serves as a combustion space in the engine and is usually lined. The three types of liners available are the dry, wet, and water-jacketed. The cylinder head seals the cylinder forming a combustion space.

All modern diesel engines, regardless of size and speed, have precision bearings consisting of thin steel, bronze, or brass shells with a lining of bearing metal. Only double-acting diesel engines require a crosshead and crosshead guide. The purpose of the crosshead guide is to take the side thrust coming from the angularity of the connecting rod which would otherwise be taken by the cylinder liner.

Section II. Main Moving Parts

2.7. GENERAL

Many of the principal parts which are mounted within the main structure of an engine are moving parts. These moving parts convert the power developed by combustion in the cylinder to mechanical energy that is available for useful work at the output shaft. This section discusses the moving and related parts that seal and compress gases in the cylinder and transmit the power developed in the cylinder.

2.8. CRANKSHAFT

One of the largest and most important moving parts in an engine is the crankshaft. The crankshaft changes the movement of the piston and connecting rod into the rotating motion required to drive such items as reduction gears, propeller shafts, generators, and pumps. As the name implies, the crankshaft usually consists of a series of crankthrows formed as offsets in a shaft. The crankshaft is subjected to all the forces developed in an engine. The principal force a crankshaft must resist is the bending action of the connecting rod thrusts when the piston is at top dead center. The maximum gas pressure acts straight down on the crankpin and tends to bend the crankshaft between the adjacent supporting bearings. The crankshaft must also withstand the twisting or torsional forces produced by the turning efforts of the connecting rod.

A crankshaft with the component parts is shown in figure 2.7. The main bearing journals serve as the points of support and as the center of rotation for the shaft. As bearing surfaces, the journals (crankpin and main) of most crankshafts are surface hardened so that a longer wearing, more durable bearing metal can be used without causing excessive crankshaft wear. Crankshafts have a main bearing journal at each end of the shaft. In most cases, there is an intermediate main bearing journal between the cranks; however, in small shafts, intermediate journals may not be necessary. Each crankthrow of a crankshaft consists of three parts: two webs and a pin. Crank webs are sometimes called cheeks or arms. The cranks or throws provide points of attachment for the connecting rods and also serve as the connecting links between main journals. In many crankshafts, especially in large engines, the crankpins and main journals are of hollow construction. Hollow construction not only reduces weight considerably, but also provides a passage for the flow of lubricating oil as pictued in figure 2.8.

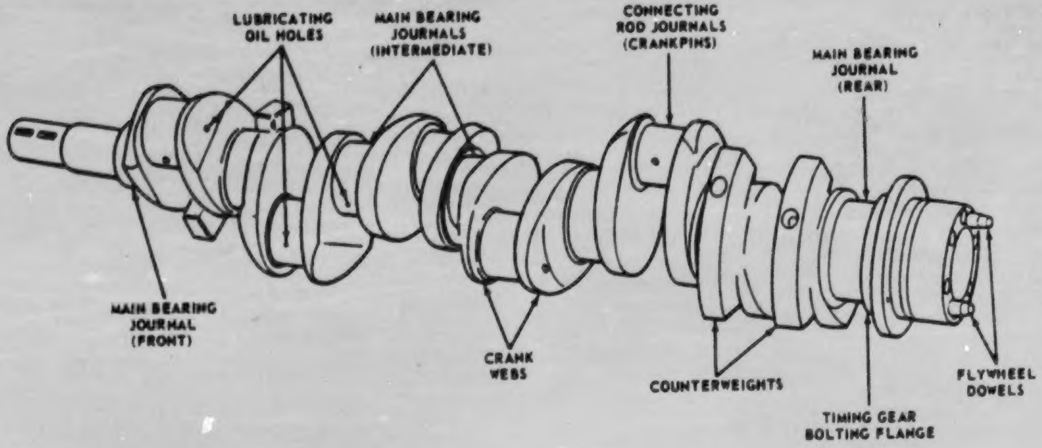

LUBRICATING OIL HOLES
MAIN BEARING JOURNALS (INTERMEDIATE)
CONNECTING ROD JOURNALS (CRANKPINS)
MAIN BEARING JOURNAL (REAR)
MAIN BEARING JOURNAL (FRONT)
CRANK WEBS
COUNTERWEIGHTS
FLYWHEEL DOWELS
TIMING GEAR BOLTING FLANGE

Figure 2.7. Crankshaft Nomenclature.

Most crankshafts are machined from forged alloy or high carbon steel. The crankshafts of some engines are made of cast-iron alloy. Forged crankshafts are nitride treated to increase the strength of the crankshaft and to minimize wear.

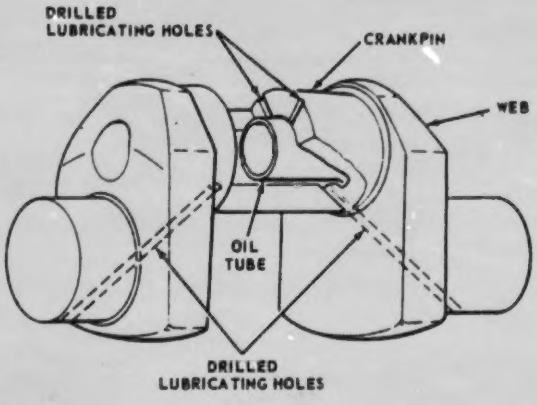

DRILLED LUBRICATING HOLES
CRANKPIN
WEB
OIL TUBE
DRILLED LUBRICATING HOLES

Figure 2.8. Hollow Crankpin and Lubricating Passages.

2.9. PISTONS

Pistons are cylindrical parts of an engine which move within the cylinders, serving first to compress the air charge at the top of the cylinder, and second to transmit the force exerted by the combustion gases through the connecting rods to the crankshaft. The motion of the piston is reciprocating; that is, it moves up and down or back and forth in a straight line. This reciprocating motion is transformed into rotary motion by connecting rods and transmitted to the crankshaft.

To fully understand the operation of a piston it is necessary to know its detailed construction. A typical piston will normally consist of the crown, skirt, grooves and lands, oil drains, and bosses as shown in figure 2.9. Some pistons are designed with cooling fins and ribs on the interior of the piston, forming cooling oil chambers.

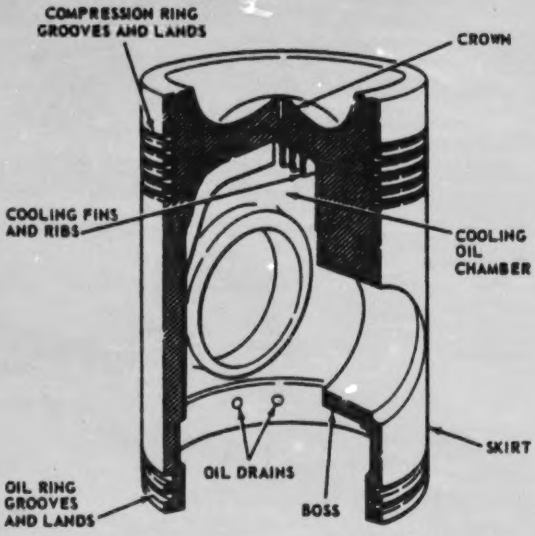


Figure 2.9. Piston Construction.

The crown or head of a piston changes the volume of the cylinder's content (compression), removes gases from the cylinder (exhaust), and transmits the force of combustion (power). Generally, the crown end of a piston is slightly smaller in diameter than the skirt end. The resulting slight taper allows for expansion of the metal at the combustion end. At normal operating temperatures, the diameter of the piston is the same throughout. To provide a sufficient cross-sectional area for heat flow, the crown is often made thicker than necessary for strength. A variety of crown designs are in use today, including turncated, cone, recessed, dome or convex, concave or cup, and flat. Piston crowns of concave design are common in marine engines. The concave shape assists in creating air turbulence, which mixes the fuel with air during the last part of compression in diesel engines. Recesses are provided in the rim of some concave pistons to allow room for parts which protrude into the combustion space. Examples of such parts are the exhaust and intake valves, the air starting valve, and the fuel injection nozzle. In some two-stroke-cycle engines, piston crowns are shaped with irregular surfaces which deflect and direct the flow of gases.

Piston skirts, like piston heads, are being made in several designs. Piston skirts may be plain or smooth, slotted or split, or knurled. In some cases, the plain skirt has a smooth bearing surface throughout the length of the piston; in others, the diameter of the skirt in the vicinity of the bosses is slightly less than that of the rest of the piston. Pistons with slotted skirts permit the skirt to expand without increasing the piston diameter at heavy sections. The knurled skirt is of relatively recent design. Knurls are small beads or serrations on a metal surface. Longer service can be expected from pistons of the knurled type because of better lubrication afforded by the oil carried by the grooves of the knurls. The skirt of a trunk piston receives the side thrust created by the movement of the crankshaft and connecting rod. In turn, the piston transmits the thrust to the cylinder wall. In addition to receiving thrust, the skirt aids in keeping the piston in proper alignment within the cylinder.

Grooves provide a mounting surface for the piston rings and the lands are used to space the piston rings on the piston to obtain the most efficient sealing qualities. The number of grooves and lands on a piston depend primarily on the piston size, type, and application.

Some pistons are constructed with oil drains (small holes) in the bottom of some of the grooves. Occasionally, oil drains are located in the skirt of the piston. These holes serve as oil returns, permitting lubricating oil from the cylinder wall to pass through the piston into the crankcase.

Generally the bosses (hubs) of a piston are heavily reinforced openings in the piston skirt. In some cases, the bosses are a part of an insert which is secured to the inside of the piston. The principle function of the bosses is to serve as mounting places for the bushing or bearings which support the piston pin. They provide a means of attaching the connecting rod to the piston. In some cases, bosses serve as the piston pin bearings. Generally, the diameter of the piston at the bosses is slightly less than the diameter of the rest of the piston. This provision is necessary to compensate for the expansion of the extra metal in the bosses.

2.10. PISTON RINGS

Piston rings are vital to engine operation and are designed to fit into the ring grooves that encircle the upper (crown) and lower (skirt) portions. The purpose of the piston rings is to effectively perform three important functions: block downward flow of the air charge or combustion gases, prevent excessive amounts of lubricating oil from reaching the combustion space, and transfer heat from the piston to the water-cooled cylinder wall. Piston rings are classified according to major services; namely, compression seal ring and oil-control ring. The number of piston rings required on a piston will vary with the type and size of the piston.

The principal function of a compression ring is to seal the cylinder during the compression and power strokes. Oil is carried with the compression rings as they perform their function. Compression rings have been designed with a variety of cross sections; however, the rectangular cross section is the most common. Since piston rings maintain pressure in a cylinder, they must possess sufficient elasticity to press uniformly against the cylinder wall. The diameter of the ring, before installation, is slightly larger than the cylinder bore. Because of a joint, the ring can be compressed to enter the cylinder. The tension created when the ring is compressed and placed in a cylinder enables the ring to expand and produce a pressure against the cylinder wall. The pressure exerted by rings near the combustion space is increased by the action of the confined gases during compression and combustion. The gases press down at the top ring, forcing it down against the land. The gases then enter behind the top ring through the side clearance between the ring and land, forcing the ring against the cylinder wall as illustrated in figure 2.10. The gas pressure on the second and succeeding compression rings is progressively less, since the gas reaching these rings is limited to the gas passing through the gap at the ring joint of the top ring.

Most compression rings are made of gray cast iron; however, some have special facings such as a bronze insert in a slot cut around the circumference of the ring or a treated surface. Rings with the bronze inserts are sometimes called gold seal rings, while those with special facings are referred to as bimetal rings. The bimetal ring consists of two layers of metal bonded together; the inner layer is steel and the outer layer is cast iron.

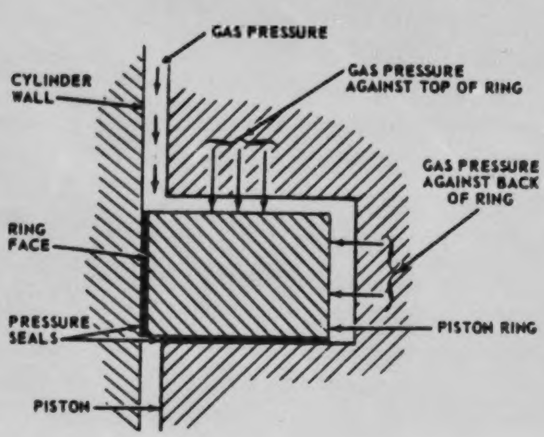

GAS PRESSURE
CYLINDER WALL
GAS PRESSURE AGAINST TOP OF RING
GAS PRESSURE AGAINST BACK OF RING
RING FACE
PRESSURE SEALS
PISTON RING
PISTON

Figure 2.10. Example of Combustion Gas Presure Effect on Piston Ring.

Standard compression rings are of single piece construction and will normally have simple joints such as the 45-degree angle joint, the straight-cut or butt joint, and the step or lap joint as shown in figure 2.11. The lap joint provides somewhat better sealing than the angle or butt joints, the butt joint is the most common and is used when operating conditions permit.

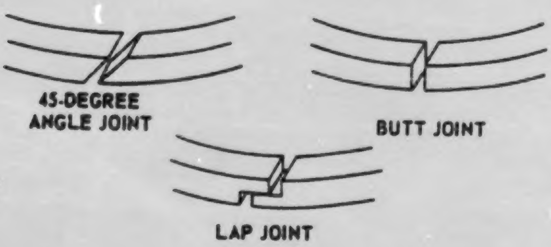


Figure 2.11. Basic Compression Ring Joints.

Special compression rings, or seal rings, are used when the ring gap at joints of conventional rings becomes larger because of ring face or cylinder liner wear. Seal rings, as their name implies, seal and prevent leakage of compression gases around the ring gap and down the cylinder bore during operation. On some high output engines, single-piece, step-type seal rings are used instead of the top standard compression rings to reduce normal compression losses. Seal rings on large engines, where considerable cylinder wear has taken place, are made in two pieces, a master and an outer ring. Figure 2.12 shows that the outer ring completely seals the joint opening of the master ring.

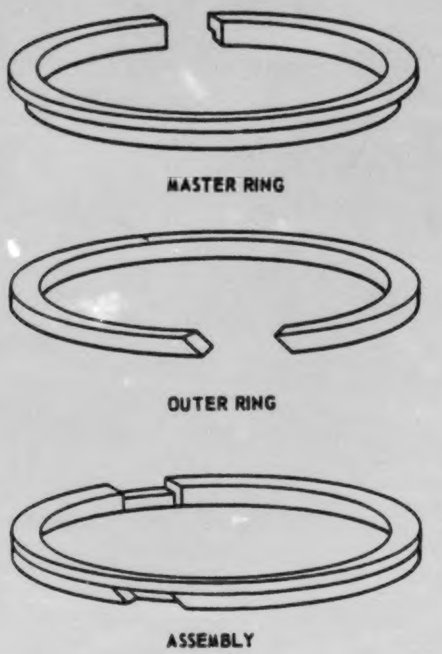


Figure 2.12. Two-Piece Seal Ring Composition.

Seal rings, being a form of compression rings, are made of the same material used in standard compression rings. During engine operation, the joints of seal rings remain closed even when the ring passes over the enlarged portion of the worn piston liner. Seal ring joints are designed to perform the sealing function.

Seal rings are made to perform their sealing function in one direction only. The top side of the seal ring is usually marked "TOP" and must always be installed with the marking toward the piston crown.

Oil control rings are usually located at the bottom end or skirt of the piston. In some engines, oil control rings are placed at the top of the skirt above the piston pin. Normally, small engines have only one oil control ring; large engines may use two or three oil control rings for each piston.

In performing their function, oil control rings prevent the upward travel of lubricating oil in excess of that required to lubricate the compression rings and cylinder or liner wall. Without an adequate oil film between the rings and the cylinder or liner wall, undue friction occurs, resulting in excessive wear of the rings and the cylinder or liner wall. If too much oil is distributed by the rings, the oil may reach the combustion space and burn. This not only results in the waste of oil, but also causes smoky exhaust and excessive carbon deposits in the cylinder. Such carbon deposits may cause the compression rings to stick in their grooves, leading to leakage of combustion gases down past the piston into the crankcase. Rings of various designs have been constructed to improve the control and distribution of lubricating oil in the cylinders of the engine.

Oil control rings are usually made of cast iron and have a narrow face to obtain a higher unit wall pressure. The edge of the face is often undercut to provide a scraping edge. There has been a growing trend toward the use of fabricated steel or stainless steel in the manufacture of oil control rings. Side rail faces of oil control rings are often chrome plated. Chrome plating is resistant to high temperatures, resists wear, and reduces the corrosion effect of combustion.

If a distinction is to be made between types of oil control rings, the terms "control" and "scraper" can be used. When this distinction is made, the control rings are those closest to the compression rings, while the oil scraper or wiper rings are those farthest from the compression rings. In some designs, the oil control ring may have a single, narrow, beveled scraping edge; in other designs, two narrow, beveled scraping edges are used.

The single-land, beveled, and grooved oil ring has a single, narrow, beveled face that presses against the cylinder wall, performing the oil control and distribution function. The bevel on the upper edge of the ring face causes the ring to ride over the oil film as the piston moves upward. As the piston moves down, the hooklike lip in the ring scrapes or wipes the oil from the cylinder wall. The excess oil is forced into a machined oil collecting groove and returned to the crankcase through drainage holes in the piston wall. In some designs, the piston skirt below the bottom oil control ring is machined smaller to provide a passage for the scraped excess oil as shown in figure 2. 13.

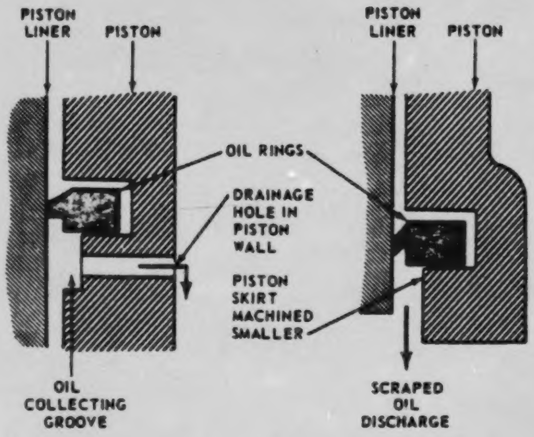


Figure 2. 13. Single-Land, Beveled, and Grooved Oil Ring.

Oil control rings designed with two scraping edges are commonly called double-land beveled, and ventilated oil rings. Double-land, ventilated rings are designed in single piece construction with slots cut through the top and bottom lands or rings faces.

The ventilating slots permit excess oil to pass through the ring to the back of the ring groove. Drain holes in the piston permit oil to flow back to the crankcase as illustrated in figure 2.14.

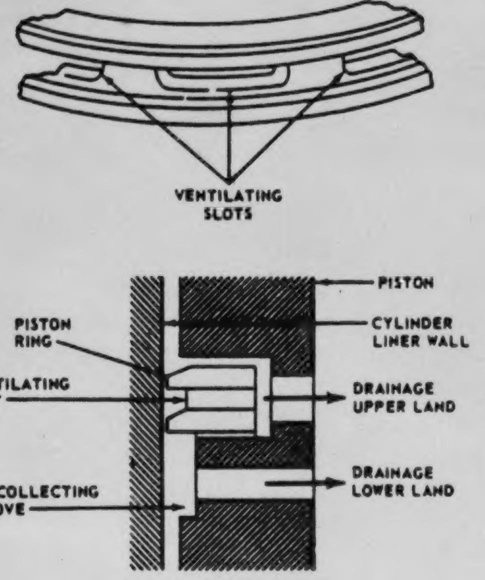


Figure 2.14. Double-Land, Beveled, and Ventilated Oil Ring.

2.11. PISTON PINS

The piston pins provide a link and a pivot point between the piston and the connecting rod. They are usually made of tubular steel alloy, machined, hardened, precision ground, and lapped to fit the bearings. In some cases, piston pins are chrome plated to increase the wear resistant qualities. Ideal piston pin construction provides maximum strength with minimum weight. Lubrication is provided by splash from the crankcase or by oil forced under pressure through passages drilled through the connecting rods.

Piston pins are secured in a piston and connecting rod in one of three methods: rigidly fastened into the piston bosses, clamped to the end of the connecting rod, or free to rotate in both piston and connecting rod. Figure 2.15 shows the piston pins secured by these three methods. They are identified as anchored or fixed pins, semifloating pins, and full-floating pins.

a. Anchored or fixed pins are secured to the piston at the bosses by a press fit or a screw running through one of the bosses. The connecting rod oscillates on the pin. Since all movement is by the connecting rod, there is uneven wear on contacting surfaces of this installation.

b. Semifloating pins are secured in the middle of the connecting rod by a press fit or they are fastened to the connecting rod by bolts. In this type, the ends are free to move in the piston pin bearings in the piston bosses.

c. Full-floating pins are not secured to either the piston or connecting rod. Pins of this type may be held in place by caps, plugs,

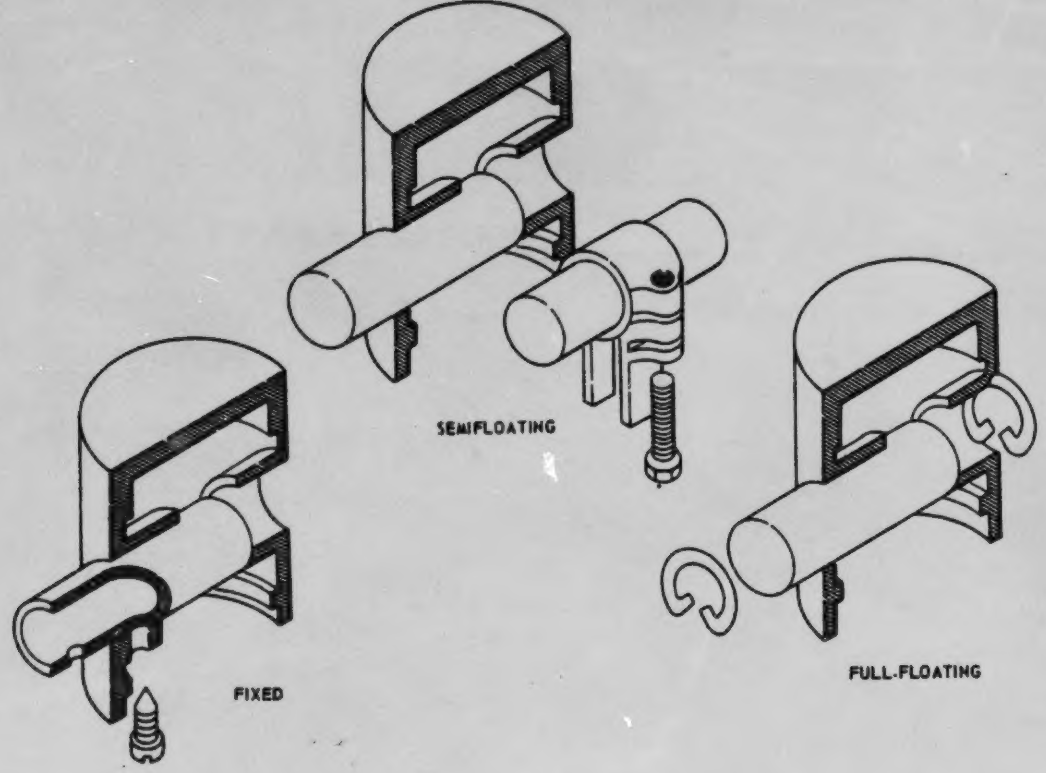


Figure 2.15. Types of Piston Pins.

snaprings, or spring clips which are fitted in the bosses. The securing devices for a full-floating pin permit the pin to rotate in both the connecting rod and piston pin bosses. The full-floating piston pin is the most commonly used of the three pin types.

2.12. PISTON RODS AND CONNECTING RODS

The piston rod is a hollow straight rod which connects the piston to the crosshead and is therefore restricted to engines designed with crossheads. Piston rod motion is straight reciprocation. Passages within the rod permit the cooling oil to enter and leave the piston as shown in figure 2.16. The connecting rod serves as the connecting link between the piston and crankshaft or the crankshaft and crosshead. In transferring the forces of combustion to the crankshaft, the connecting rod changes the reciprocating motion of the piston to the rotating motion of the crankshaft. Figure 2.17 shows that the type of connecting rod used in an engine depends on cylinder arrangement and type of engine.

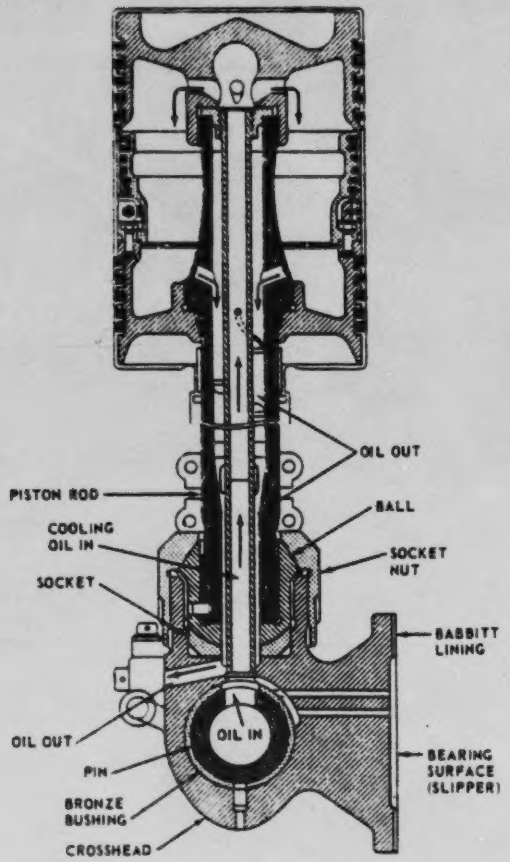

OIL OUT
PISTON ROD
BALL
COOLING OIL IN
SOCKET NUT
SOCKET
BABBITT LINING
OIL IN
OIL OUT
PIN
BEARING SURFACE (SLIPPER)
BRONZE BUSHING
CROSSHEAD

Figure 2.16. Piston Rod and Crosshead Assembly.

Piston rods and connecting rods are generally made of drop-forged, heat-treated, carbon steel (alloy steel forging). The rods are usually machine finished and drilled hollow axially to reduce overall weight and provide an oil passage for bearing lubrication.

Piston rods usually have a tubular type construction. Connecting rods, in most cases, have an I or H shaped cross section which provides maximum strength with minimum weight. The bore (piston pin eye) at the piston end of the connecting rod is forged as an integral part of the rod. The bore at the crankshaft end is formed by two parts, one an integral part of the rod and other a removable cap. The bore at the crankshaft end is fitted with a precision, shell-type bearing.

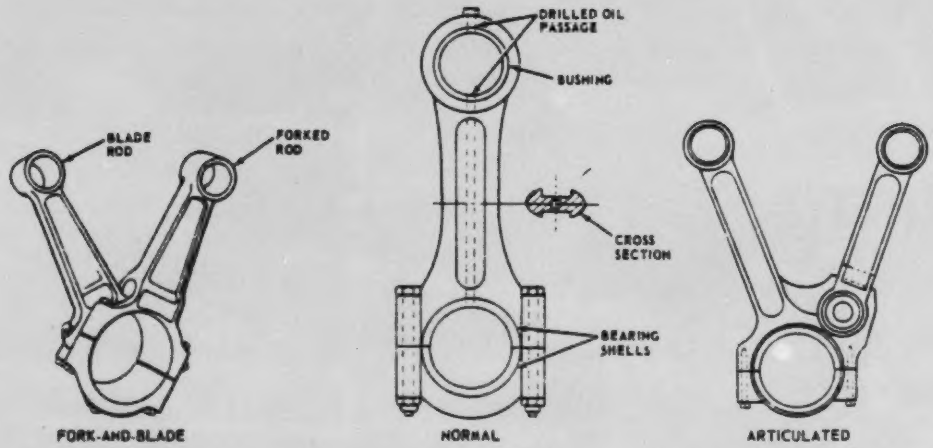

BLADE ROD
FORKED ROD
DRILLED OIL PASSAGE
BUSHING
CROSS SECTION
BEARING SHELLS
FORK-AND-BLADE
NORMAL
ARTICULATED

Figure 2.17. Types of Connecting Rods.

2.13. SUMMARY

Because of the high pressures and temperatures developed in diesel engines, the various parts must be extremely durable. The crankshaft changes the movement of the piston and connecting rod into rotating motion. It is kept at the shortest length possible for its particular engine and is made of strong alloy steels.

The pistons are cylindrical parts of an engine which move within the cylinders, serving first to compress the air charge at the top of the cylinder, and second, to transmit the force exerted by the combustion gases through the connecting rods to the crankshaft. They are cast with interior ribs to withstand the pressure created in the cylinder produced by ignition of the fuel. Most pistons in marine diesel engines have a concave-shaped crown to produce air turbulence. Piston rings are vital to engine operation and are designed to fit into the ring grooves that encircle the crown and skirt of the piston. They serve three purposes: block downward flow of combustion gases, prevent excessive amounts of lubricating oil from reaching the combustion space, and transfer heat from the piston to the water-cooled cylinder liner. Most compression rings are made of grey cast iron.

Piston pins provide a link and a pivot point between the piston and connecting rod. They are usually made of tubular steel. The three types of piston pins are the fixed, semifloating, and full-floating. The connecting rods, regardless of configuration, are used to transmit the power created by ignition to the crankshaft.

Chapter 3

VALVE GEAR

3.1. INTRODUCTION

The valve gear consists of a combination of parts, including the various valves which control the admission of the air charge in four-stroke engines, the discharge of exhaust gases in all four-stroke and many two-stroke engines, the admission of fuel in some diesel engines, and the admission of compressed air for starting all larger engines. The combination of those parts, which only operate the various intake, exhaust, fuel, and air starter valves, open and close them at the proper moment in relation to the position of the piston, and hold them open during the required time, is called the valve actuating gear. The word "actuating" means producing action or moving.

3.2. CAMS AND CAMSHAFT

A cam is an eccentric projection on a revolving disk which controls the operation of a valve, usually through various intermediate parts as described in the preceding paragraph. Originally cams were made as separate pieces and fastened to the camshaft. However, most modern diesel engines, even in larger sizes, now have cams forged or cast integral with the camshaft and then machined. The camshaft is similar to the one in an automobile engine. If one cylinder is timed correctly, all are, and any change in timing will affect all cylinders.

In operation, cams are subjected to shock action; to reduce wear, they must be hardened. The shape of the cam determines the points of opening and closing of the valve, the speed of opening and closing, and the amount of the valve lift. The required cam shape or profile surface is obtained by accurate grinding. The sides of a cam are called flanks; the highest part is called the nose. The cam may have flanks curbed outward, called convex-curve flanks. Figure 3.1 shows cams with straight sides, called tangential flanks.

Figures 3.1a and b are typical intake and exhaust cam shapes for four-stroke engines and 3.1c is an exhaust cam for a two-stroke engine.

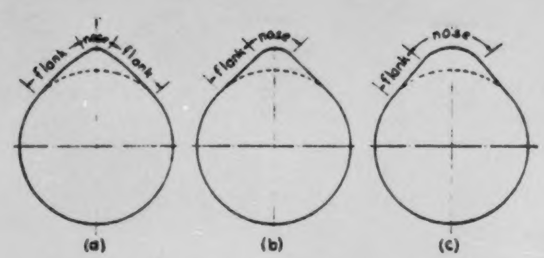


Figure 3.1. Profiles of Intake and Exhaust Cams.

Figure 3.2a illustrates an adjustable fuel-injection cam as used on four-stroke engines with a common-rail or similar injection system in which the nose may have to be exchanged and the injection accurately timed. Chapter 4 explains the common-rail system in detail. The nose is made in the form of a hardened steel insert i, held by a set screw s, and blocks or keys k, which can be filed to obtain the exact location of the nose. Figure 3.2b shows a fuel-injection cam as used on a two-stroke engine with a unit injector.

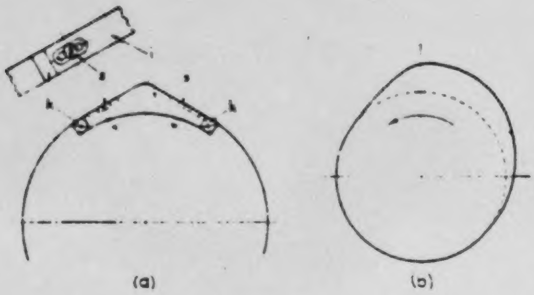


Figure 3.2. Fuel-Injection Cams.

Figure 3.3a shows the typical shape of the cam for the air-starter valve of a four-stroke engine; it has a quick and abrupt lift which gives full valve opening almost immediately, and prevents throttling of the compressed air through the starting valve. A gradual seating of the valve is obtained by the smoother shape on the closing side. Figure 3.3b illustrates an air-starting cam for a high-speed two-stroke diesel engine.

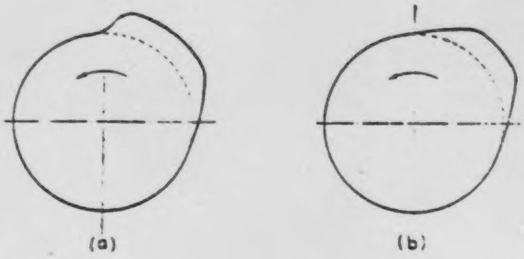


Figure 3.3. Air-Starting Cams.

A four-stroke engine has at least two cams for each cylinder, one for the intake and the other for the exhaust valve. Depending upon the fuel-injection system used, there may be another cam to operate the fuel-injector, and if air-starting is used, still another cam for the air-starting valve. If the engine is reversible, another set of cams is used for the other direction of rotation of the engine, resulting in as many as eight cams per cylinder. A two-stroke engine does not have a cam for the intake, but if exhaust valves are used, at least two exhaust valves per cylinder are present which may be operated either by common or two separate cams, so that the number of cams is about the same as in a four-stroke engine.

As already mentioned, in some engines the camshaft is a straight round shaft and the cams are separate pieces, machined and keyed to the shaft. However, in most modern diesel engines the cams and the shaft are forged or cast in one piece. In some larger engines the integral camshafts are made up of two or more sections to facilitate replacement in a restricted space. The sections are bolted together by flanges with fitted reamed holes to assure accurate timing. Most camshafts are made of forged steel, usually of nickle-chromium alloy steel, and the larger ones are usually bored hollow. They are heat treated and in some cases the cams are surface hardened. The camshafts are carried in plain bearings.

Camshafts are driven from the engine crankshaft by various means. Figure 3.4a shows a drive by a train of straight spur gears used in most marine diesel engines. Figure 3.4b shows a drive by two pairs of helical or screw gears and an intermediate vertical shaft; figure 3.4c, a similar drive but using two pairs of bevel gears. Figure 3.4d shows a chain drive; d is the crankshaft; p, the sprocket keyed to it; g, the camshaft sprocket; and m, the camshaft.

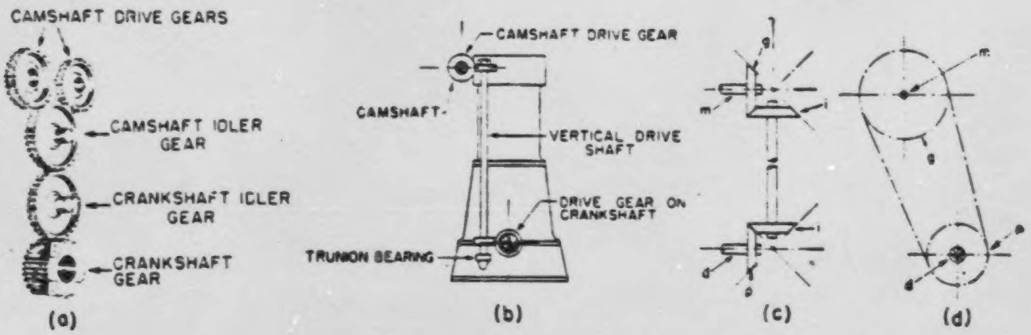

CAMSHAFT DRIVE GEARS
CAMSHAFT IDLER GEAR
CRANKSHAFT IDLER GEAR
CRANKSHAFT GEAR
(a)
CAMSHAFT DRIVE GEAR
CAMSHAFT
VERTICAL DRIVE SHAFT
DRIVE GEAR ON CRANKSHAFT
TRUNION BEARING
(b)
g
m
i
i
d
p
(c)
m
g
p
d
(d)

Figure 3.4. Types of Camshaft Drives.

In two-stroke engines the camshaft rotates at the same speed as the crankshaft, while in four-stroke engines it rotates at half crankshaft speed.

3.3. CAM FOLLOWERS

Modern diesel engines use several types of cam followers: flat or mushroom, roller, or pivoted as illustrated in figure 3.5.

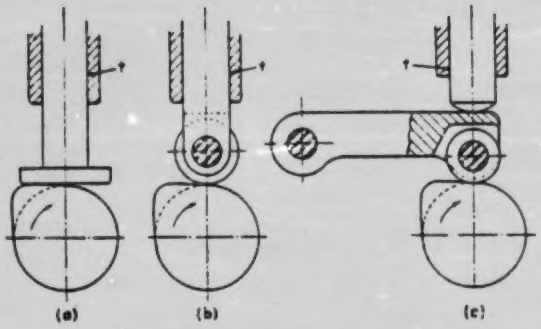


Figure 3.5. Cam Followers.

The combination of the convex-flank cam with the flat mushroom follower causes a considerably faster valve opening and closing and is used on smaller engines, running at higher speeds. The disadvantage of this type of follower is a faster acceleration which results in higher inertia forces. On the other hand, this combination gives a lower deceleration of the valve assembly as the latter approaches the top or nose of the cam, and consequently requires somewhat smaller spring forces to prevent bouncing of the valve gear. Bouncing of the valve gear occurs after it has reached the maximum acceleration point during the lifting of the valve, and from then on it must be decelerated as the follower nears the top of the lift at the nose of the cam. The inertia of the valve gear at this point tends to lift the valve faster than the cam action. If the valve spring does not have enough force to decelerate the moving parts of the valve gear at the same rate as the contour of the cam, the follower will leave the surface of the cam, if only for an instant. When it makes contact again, it does so with considerable shock, causing pounding and excessive stresses and wear in various parts of the valve gear. This is called bouncing and is undesirable. The sliding part, t, of a follower which moves up and down in a bored hole above the cam and takes the side thrusts exerted by the cam is called a valve lifter or tappet.

The action of the pivoted follower resembles the roller follower. Its main advantage is that the side thrust from the cam is taken by the pivot of the lever arm instead of by the sliding tappet as with the other types. The rollers of the followers are made of steel, hardened and accurately ground to size and to a circle. It is important that the rollers have little or no play and that they remain concentric, meaning that the center of the outside circle and of the hole in one roller are at the same point.

3.4. ROCKER ARMS AND PUSH RODS

The rocker arm has one end in contact with the top of the valve stem, and the other end, by means of a hardened-steel roller, is in contact with the rotating cam profile as it rotates if the camshaft is near the cylinder head. If the camshaft is located below the other end of the rocker arm, it is contact with the upper end of the push rod; the lower end of the push rod is in contact with the rotating cam through a cam follower. In most designs, the rocker arm is pivoted, not always at or near its middle, and the pivot pin is held in brackets secured to the cylinder head.

When two or more valves of a cylinder must be opened and closed at the same time, as in the case of the exhaust valves of some General Motors Corporation two-stroke engines, one rocker arm may be used to operate two valves by acting upon a "bridge" between the valve stems. The bridge has special cams in contact with the valve stems, and a lower extension acting as a guide. An auxiliary spring is used under the bridge to offset its inertia and that of the rocker arm, and to assist the valve springs in maintaining the cam follower in contact with the cam at all times.

3.5. VALVES

The intake and exhaust valves used in diesel engines are the mushroom-shaped, poppet type as shown in figure 3.6. The valve assembly consists of a valve, valve spring, valve lock retainer, valve spring lock, valve stem cap, and lockring. The purpose of the valve spring is to hold the valve to the machined valve seat to insure a tight fit.

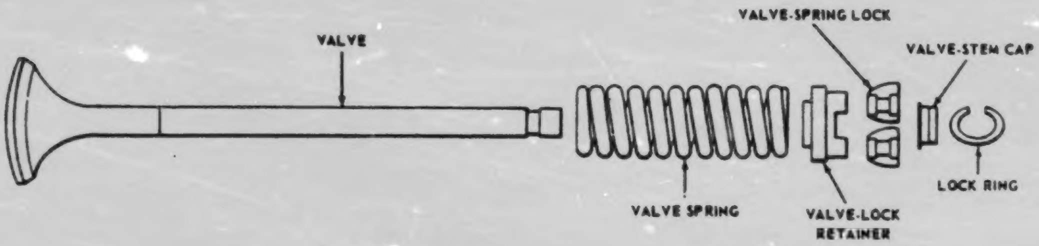


Figure 3.6. Poppet Valve Assembly.

Poppet valves have heads with conically shaped or beveled edges and beveled seats which give them self-centering action. The bevel seats on poppet valves of most engines are ground to an angle of 45° to the flat side or plane of the valve head. On some they are ground to an angle of 30°.

The material used to make an intake valve is usually carbon or nickle steel. Although the intake valve is subjected to the heat of combustion, sufficient cool air flows over it when the valve is open to maintain a workable temperature. Exhaust valves present a different problem from that of the intake valve. Instead of being cooled by low temperature air like the intake valve, the exhaust valve is being constantly engulfed in hot exhaust gases and corrosive temperatures of these gases. Silicon-chromium steel (silichrome) is the material usually used for exhaust valves. Often a special material such as stillite is welded to the seating surface of the valve head as well as to the tip of the valve stem. This increases the hardness of the surfaces that are subjected to the constant pounding of opening and closing. To improve the wearing qualities of the valve stem, which usually operates in a valve guide of softer metal, the stems of many exhaust valves are made of a steel different from that used for the heads. The stems are welded to the heads to form built-up valves.

Valve guides act as a bearing surface for the up-and-down motion of the valve stems. These cylindrical sleeves are installed by driving them into place from the tops of the cylinder, using a tool designed for that specific engine. This tool serves as a stop for properly positioning the guides in the head so that the lower end of the guide is flush with the top of the specific valve. The guides are installed with the countersunk ends upward. After installation, they are reamed to close tolerances with the valve stems to preclude any gas leakage passing down from the valve chambers. Additionally, this close valve stem guide clearance allows for the true seating.

All poppet valves formerly were seated directly on the surface of the cylinder head. This practice is still satisfactory for most intake valves, but usually will not give good service for exhaust valves of high temperature engines. Cast-iron seating surfaces tend to soften and erode under the high temperature caused by the heat transfer from exhaust gases and contact with the hot exhaust valves. To increase the life of exhaust valves, most engines now have valve seat inserts installed. Valve seat inserts can be used with both intake and exhaust valves, but are more frequently used with exhaust valves only. These inserts are rings of a heat-resisting alloy which fit into counterbored recesses in the valve port opening. They are held in place by a shrink or press-fit of 0.0005 to 0.0025 inch. The alloy used in inserts has approximately the same rate of heat expansion as the cylinder head; therefore, the insert is held firmly in place at all operating temperatures.

Valves for large engines sometimes are assembled in cages, which carry the valve, the seat insert, stem guide, and spring. The cage is removable from the cylinder head as a unit and is usually water cooled. The cage is normally made of cast iron. A worn seat insert can be removed from the cage and replaced.

3.6. VALVE SPRINGS

A valve spring closes the valve. Valve springs used on diesel engines are made of round steel wire, wound in a helical coil, as shown in figure 3.6. Springs of this type have a force which is directly proportional to the amount they are compressed. Only a small portion of the maximum valve spring force is necessary to keep the valve tight on its seat. The principal duty of the valve spring, as mentioned before, is to provide sufficient force during the valve lifting process to overcome the inertia forces of the valve gear and keep it in contact with the cam without bouncing. This is obtained by putting the spring under compression when the valve is installed. When the valve is opened, this force is increased by additional compression of the spring.

The space available for the valve spring is limited and therefore it is not easy to design and construct a spring which will exert the necessary force and still not break under the constantly repeated change of stresses. A spring made of wire with a small diameter is subjected to less stress than one made of wire with a larger diameter, but it also has a smaller force. In some engines two or more valve springs with a small wire diameter are used to operate the valve gear.

Valve springs are mounted between supports located at their ends and known as spring seats. The lower spring seat may be simply a recess in the top of the cylinder head or valve cage, or it may be a steel washer which rests on top of the cylinder head and is shaped to fit the bottom coil of the spring. The upper spring seat, called the spring or valve-lock retainer, is a steel washer shaped to fit the top of the spring and attached to the top of the valve stem by a removable fastening.

The most widely used spring retainer has a conical recess in the upper seat in which the valve stem is locked by a conical split collar, called a lock or keeper. This collar fits around the stem and into one or more grooves turned in the valve stem, as shown in figure 3.7.

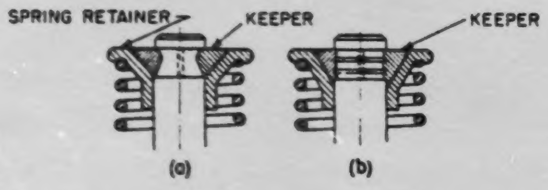


Figure 3.7. Valve-Spring Retainers.

The pressure of the spring on this retainer tends to hold the locks tightly in place; yet they may be removed easily by depressing the spring while holding the valve in its closed position. There are two advantages to this type of retainer and keeper: first, they do not loosen in service; and second, they give a strong fastening which does not result in weakening of the valve stem, which frequently occurs when other types of fastenings are used. Some large diesel engines use valve spring retainers held in place by a lock nut which screws into threads on the upper end of the valve stem.

3.7. VALVE LASH AND ADJUSTMENT

When the engine heats, the expansion of the valve stem and other parts of the valve gear have a tendency to hold the valves off their seats. Some provision, therefore, must be made in the valve gear to take care of this condition. The most common method used to permit this expansion is to provide a clearance or lash between the top of the valve stem and the valve-lifting mechanism. The proper lash is determined at the factory and is given in the engine instruction book. It is important that the valve lash specified for the valve be maintained. Too much lash causes noisy operation and excessive wear. It also results in improper valve timing, since the valve will open later and close sooner than it does with the proper lash. Too little lash is even more serious since it may prevent the valve from seating properly. This will result in valve leakage and burning of the valve-seating surfaces, and may even prevent combustion because of loss of compression.

All engines are provided with means for adjusting the lash or clearance in the valve gear somewhere between the cam follower and the valve stem. In most engines this adjustment consists of an adjustable screw and lock nut located at one end of the valve rocker arm. The clearance is measured directly by inserting a feeler gauge between the tip of the valve stem and the rocker-arm roller. The types of lash adjusters are explained in the following three subparagraphs.

a. Automatic valve-lash adjusters are used to avoid the necessity of a clearance between the cam and the follower regardless of whether the engine is cold or warm and, by insuring a constant contact between the cam and the follower, to eliminate the shock action at the beginning of the valve opening. They also eliminate the need for manual adjustment to take care of the wear at various points of the valve gear.

b. A mechanical valve-lash adjuster is incorporated in the valve bridge. A spiral spring has a tendency to turn the cam, as shown by the arrow in figure 3.8, when the cylindrical spring pushes the bridge to its highest position. The spring takes up any clearance

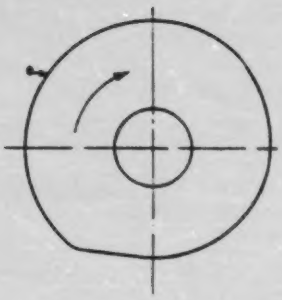


Figure 3.8. Cam of a Mechanical Lash Adjuster.

between the various parts of the valve-actuating gear, and the turning of the cams takes up clearance between the ends of the bridge and the upper spring seats solidly connected to the valve stem.

c. Hydraulic lash adjusters may be built into the valve tappets, but with valve-in-head engines they are generally built into the end of the rocker arms or the valve bridges which operate directly on the ends of the valve stems. Figure 3.9 illustrates such an adjuster. It consists essentially of a small cylinder, referred to as the lifter cylinder, containing a piston or plunger, a spring, and a ball check valve. It is positioned between the push rod and the rocker arm end. In operation, oil under pressure from the lubricating oil system enters the lifter cylinder past the ball check valve and is trapped under the plunger. Any force exerted against the outer end of the plunger is transmitted to the cylinder, mounted in the valve gear, by the entrapped oil. The valve is thus actuated just as if the lash were taken up mechanically. Since the spring inside of the cylinder acts to force the plunger outward, any clearance between the valve and its lifter is taken up, and the oil pressure immediately fills up the lifter cylinder through the check valve. If the valve stem expands, there is sufficient leakage of oil past the plunger to permit it to move in slowly so there is no danger of holding the valve open.

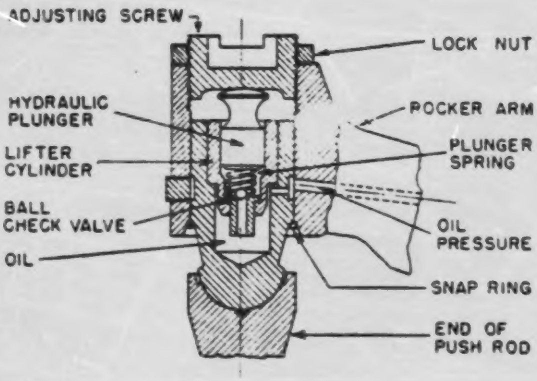


Figure 3.9. Hydraulic Lash Adjuster.

3.8. SUMMARY

The operation of the valves in a diesel engine is started by the cams fixed to the rotating camshaft. The movement is transferred to the valve by the valve gear. The first piece of the valve gear is the cam follower which makes contact with the cam. The cam follower can be one of three types: flat or mushroom, roller, or pivoted. The next piece of gear is the push rod which transmits the motion from the cam follower to the rocker arm. The rocker arm is pivoted in its middle and is pushed by the push rod on one arm and operates the valve with the other.

The valve and its mechanism consist of the valve, valve spring, valve-lock retainer, valve-spring lock, and lockring. The valve can be adjusted for lash or play by three methods: mechanical adjuster, hydraulic adjuster, or automatic adjuster.

The mechanical valve-lash adjuster is incorporated in the valve bridge. A spring takes up any clearance between the various points of the valve-actuating gear. The hydraulic lash adjuster may be built into the valve tappets, but with valve-in-head engines they are generally built into the end of the rocker arms or the valve bridges which operate directly on the ends of the valve stems. Automatic valve-lash adjusters are used to avoid the necessity of a clearance between the cam and the follower regardless of whether the engine is cold or warm and, by insuring a constant contact between the cam and the follower, to eliminate the shock action at the beginning of the valve opening.

Chapter 4

FUEL INJECTION SYSTEMS

4.1. INTRODUCTION

The fuel injection system is the most intricate of all systems affecting the operation of a diesel engine. Originally there were two methods of fuel injection: air injection and mechanical or solid injection. Air injection is now obsolete. Mechanical injection may be divided into three distinct systems--common-rail, individual-pump, and distributor. Because this is a basic course, the study of fuel injection systems covers only fundamental principles. A more detailed study is found in Reference Text 447.

4.2. REQUIREMENTS OF FUEL INJECTION SYSTEMS

Efficient operation of a diesel engine requires that the fuel injection system perform the functions outlined in subparagraphs a through e. The means of performing these functions vary according to the system used.

a. Metering or measuring of the fuel means that, for any given throttle setting, the same amount of fuel delivered for each ~~cycle must be in~~ accordance with the engine requirement, and exactly the same amount of fuel must be delivered to each cylinder for each power stroke. Only in this manner will the engine operate at uniform speed with a uniform power output.

b. Timing means accomplishing fuel injection at the correct point and time in the cycle at all engine speeds and loads. This is essential to obtain maximum power from the fuel and insure clean burning. When the fuel is injected too early in the cycle, ignition may be delayed because the temperature at this point is not high enough. An excessive delay causes rough and noisy operation of the engine and permits fuel to be lost through wetting of the cylinder walls and piston head. Unburned fuel may accumulate, producing excessive pressure and resulting in noisy operation and poor fuel economy. When fuel is injected too late in the cycle, all the fuel is not burned until the piston is well into the power stroke. When this happens, the engine does not develop its maximum power, the exhaust is hotter than normal, and the fuel consumption is high.

c. Rate of injection is the amount of fuel that is injected into the combustion chamber in a particular time or degree of crankshaft rotation. When the rate of injection is too high, a metered amount of fuel is injected in too short a period, or during an insufficient number of degrees of crankshaft rotation. When it is desired to decrease the injection rate, a nozzle tip with smaller holes is used to increase the duration of fuel injection. The effective rate of injection upon engine operation is similar to that of timing. When the rate is too high, the results are similar to an early injection. When the rate is too low, the results are similar to excessively late injection.

d. Atomization is the breaking up of the fuel stream into a fine, mistlike spray. Some combustion chambers require a very fine atomization, while others operate with a coarser atomization. Proper atomization facilitates the starting of the burning process and insures that each minute particle of fuel is surrounded by oxygen for efficient burning.

e. Distribution of the fuel must be such that the fuel will penetrate throughout the combustion chamber where oxygen is available for combustion. If the fuel is not properly distributed, some of the oxygen will not be used and the power output of the engine will be low.

4.3. COMMON-RAIL INJECTION SYSTEMS

The basic common-rail system consists of a high pressure pump which discharges fuel into a common rail or header to which each fuel injector is connected by tubing. A spring-loaded bypass valve on the header maintains a constant pressure in the system, returning all excess fuel to the fuel supply tank. The fuel injectors are operated mechanically, and the amount of diesel fuel oil injected into the cylinder during each power stroke is controlled by the lift of the needle valve in the injector. The principal parts of a basic common-rail system are shown in figure 4.1.

The pressure regulator, which functions as a relief valve, is generally built integral with the high pressure pump. When the engine load drops off, the fuel consumption decreases and the valve bypasses the excess diesel fuel oil delivered by the pump. When a load is added resulting in increased fuel consumption, the amount of bypassed oil is reduced.

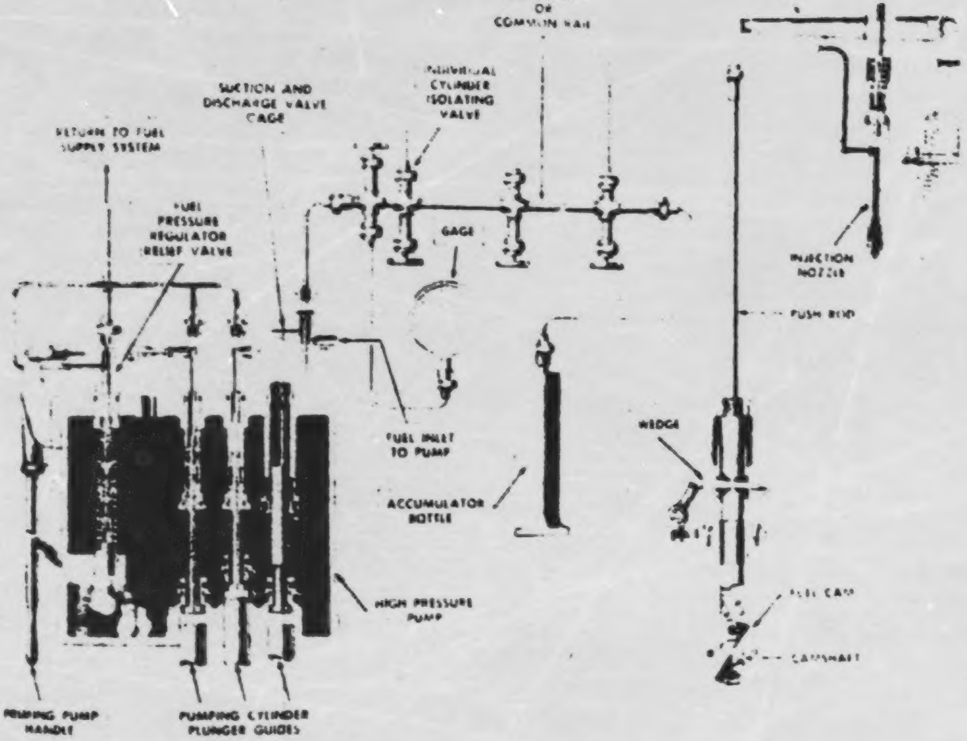

FUEL HEADER OR COMMON RAIL
INDIVIDUAL CYLINDER ISOLATING VALVE
SUCTION AND DISCHARGE VALVE CAGE
RETURN TO FUEL SUPPLY SYSTEM
FUEL PRESSURE REGULATOR RELIEF VALVE
GAGE
INJECTION NOZZLE
PUSH ROD
WEDGE
FUEL INLET TO PUMP
ACCUMULATOR BOTTLE
HIGH PRESSURE PUMP
FUEL CAM
CAMSHAFT
PRIMING PUMP HANDLE
PUMPING CYLINDER PLUNGER GUIDES

Figure 4.1. Basic Common-Rail System (Cooper-Bessemer).

The spray or injection nozzle extends from the top of the cylinder head down into the combustion area. It consists essentially of a multiple-spray tip, a valve seat, and a needle valve extending the full length of the nozzle and held to its seat by a spring. The high pressure is conducted from the fuel header to the spray tip, immediately above the valve seat. When the needle valve is lifted vertically from its seat, fuel is sprayed into the combustion chamber.

The duration of the injection periods depends upon the length of time the valve is off its seat. The quantity of fuel injected depends upon the period of injection, the size and number of holes in the tip, and the operating pressure. The needle valve is lifted mechanically by a system of push rods and cross rods, actuated by a timed camshaft. The duration period of the needle valve opening depends upon the clearance between the cam and push rod mechanism. A minimum clearance promotes a greater needle valve lift; a maximum clearance carried to the extreme will not transmit the cam lift to the needle valve, as is the case when the throttle is in the OFF position. A wedge mechanism, located between the cam and push rod mechanism controls the amount of clearance and affects cam lift. Figure 4.2 shows a fuel control mechanism.

On some engines, the wedge is located between the cross rod and the injection needle valve. When the wedges are pushed in all the way, a minimum clearance exists. The inclined plane of the cam contacts the needle opening push rod sooner and raises the nozzle needle earlier. Since the contour of the closing side of the cam is usually the same as that of the opening side, the needle returns to its seat an equal number of crankshaft degrees late as it was degrees early in opening.

The wedges are attached to a single shaft which is coupled to the governor or engine throttle, depending on the service of the engine. Consequently, they are moved in or withdrawn as the engine load changes to increase or decrease cam to push rod clearance and vary the duration of injection, as needed, to meet the demands of the engine.

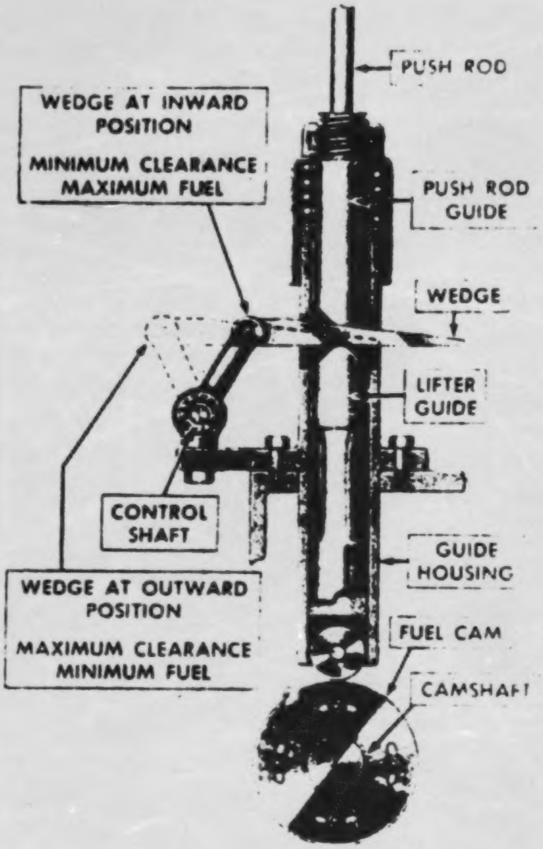

PUSH ROD
WEDGE AT INWARD POSITION
MINIMUM CLEARANCE MAXIMUM FUEL
PUSH ROD GUIDE
WEDGE
LIFTER GUIDE
CONTROL SHAFT
GUIDE HOUSING
WEDGE AT OUTWARD POSITION
MAXIMUM CLEARANCE MINIMUM FUEL
FUEL CAM
CAMSHAFT

Figure 4.2. Fuel Control Mechanism.

Engine performance is affected by the duration of the injection period. A shorter period is advantageous in starting the engine or when running at light loads. A longer period is necessary at greater loads.

An isolating valve is located in the line from the common header to each nozzle. Having individual cylinder isolating valves permits shutting off any one of the nozzles. The fuel injection system has an accumulation bottle on the pressure side of the pump to increase the volume of fuel in the system. A large volume of oil dampens the pumping pulsations and maintains a constant supply on the header.

The common-rail system is not suitable for high-speed, small small bore engines because it is difficult to accurately control the small quantities of fuel injected into each cylinder at each power stroke.

4.4. INDIVIDUAL-PUMP INJECTOR SYSTEM

Individual-pump systems are designed to meet the demands of modern, high-speed engines. This system, also known as the jerk-pump system, has two essential parts to each cylinder, the injection pump and the spray nozzle. The injection pump raises the pressure, meters the charge, and times the injection. An individual pump serves each cylinder on large engines. The pump or pump cylinder is connected to a spray nozzle containing a spring-loaded check valve.

In most jerk pumps, the total plunger stroke is constant and the metering is controlled by varying the length of the effective part of the plunger stroke by one of the following methods:

a. The fuel is admitted into the pump barrel through ports in the barrel controlled by a spiral groove or scroll, also called the helix on the plunger. The plunger can be turned in the barrel while moving back and forth. This changes the portion of the plunger stroke during which the ports are covered and the fuel is delivered to the nozzle.

b. The fuel is admitted into the pump barrel through ports in the barrel controlled by a separate valve.

The principle of the plunger-controlled pump can be better understood by referring to figure 4.3. At the bottom of the stroke, the suction and pressure release ports are both in communication with the inner pump space. When the plunger has moved a certain distance and covered both ports, fuel delivery begins with a jerk and lasts until the lower edge of the spiral begins to uncover the release port. At that point, the pressure drops and fuel delivery stops. The plunger continues to travel

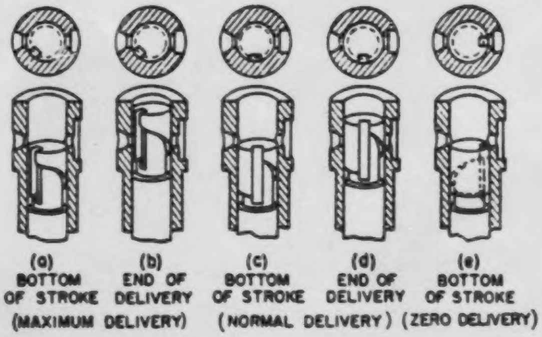


Figure 4.3. Barrel With Various Plunger Positions.

a short distance to the top of its stroke and then begins to move downward. If the plunger is turned about 60°, the distance between the top edge of the plunger and the edge of the spiral sliding over the release port is shorter, and the fuel delivery stops earlier. Finally, if the plunger is turned 90° more, the release port stays uncovered and no fuel is delivered.

In the operation as shown in figure 4.3, the beginning of the effective stroke always occurs at the same moment, but the end of the injection changes with the engine load. It is later with a higher load, greater fuel delivery, and earlier with a lower load, smaller fuel delivery. The middle of the injection stroke is advanced with a load increase.

This condition can be reversed by making a spiral edge at the top of the plunger and a square groove at its bottom. In this case the beginning of the injection will be earlier with an increase in the load and later with a decrease in it, while the end will be always constant. The middle of the injection is retarded with an increase of the load, a condition, which however, is not desirable. By making both edges spiral, inclined in opposite directions, the middle of the injection stroke can be kept constant for all loads.

Naturally, the compressibility of the fuel and the mechanical flexibility in the pump mechanism retards the actual start of injection into the cylinder, producing an injection lag.

4.5. FUEL NOZZLES

The nozzles are either the open or the closed type. The open type usually is a simple spray nozzle with a check valve which prevents the high-pressure gases in the engine cylinder from passing to the pump. Although the open nozzle is simple in construction and operation, it is not generally used because it does not fully atomize fuel. The closed nozzle is used more commonly. Basically, it is a hydraulically operated, spring-loaded needle valve. Most closed nozzles open inward under the pressure acting on the differential area of the needle valve. They are seated by a spring when the pressure is cut off, as shown in figure 4.4. The larger cylindrical part of the valve has a lapped fit with the nozzle body. The two main types of such nozzles are the pintle and the hole. The valve of the pintle nozzle, as illustrated in figure 4.5a and b, has a pin or pintle protruding from the hole in the bottom of the nozzle, causing a close fit. The fuel delivered by such a nozzle must pass through an annular or ring-shaped orifice. The spray is in the form of a hollow cone, whose outside angle, which may be any angle up to 60°, is

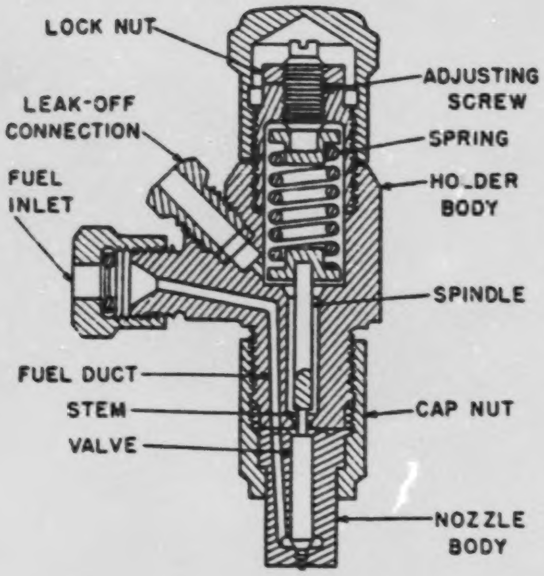

LOCK NUT
LEAK-OFF CONNECTION
FUEL INLET
FUEL DUCT
STEM
VALVE
ADJUSTING SCREW
SPRING
HOLDER BODY
SPINDLE
CAP NUT
NOZZLE BODY

Figure 4.4. Bosch Fuel-Injection Nozzle.

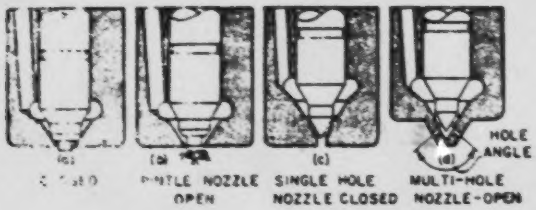

(a)
CLOSED
(b)
PINTLE NOZZLE OPEN
(c)
SINGLE HOLE NOZZLE CLOSED
(d)
MULTI-HOLE NOZZLE-OPEN
HOLE ANGLE

Figure 4.5. Types of Closed Nozzles.

determined by selecting certain dimensions. A valuable feature of the pintle nozzle is its self-cleaning property, which prevents carbon deposits from building up in and around the orifice.

As shown in figure 4.5c and d, the hole-type nozzle may have one spray orifice or it may have several. The one with several orifices, called a multi-hole nozzle, has round holes drilled through the tip of the nozzle body below the valve seat. The spray from the single-hole nozzle is relatively dense and has a greater penetration. The general spray pattern of a multi-hole nozzle, which may or may not be symmetrical, is determined by the number, size, and arrangement of the holes. Orifices used are from 0.006 inch up to 0.0225 inch in diameter, and their number may vary from three up to as many as 18 holes per nozzle for large-bore engines. Multi-hole nozzles are used generally in engines with an individual combustion chamber.

Figure 4.4 shows a pintle nozzle assembled in a nozzle holder with the spring and connections for the fuel-pressure line and leakage drain. The pressure necessary to open the needle valve may vary from 1,500 psi to about 3,000 psi.

4.6. UNIT INJECTOR

The unit injector combines a pump and a fuel-spray nozzle in one unit, as shown in figure 4.6. It is a jerk pump with ports controlled by helical-grooved edges in the plunger. The amount of fuel is controlled by turning the plunger. Figure 4.6 shows an open nozzle with a spherical check valve. The spray tip has several small orifices. However, unit injectors are also in existence which have closed nozzles with hydraulically operated differential needle valves and multi-hole nozzle tips.

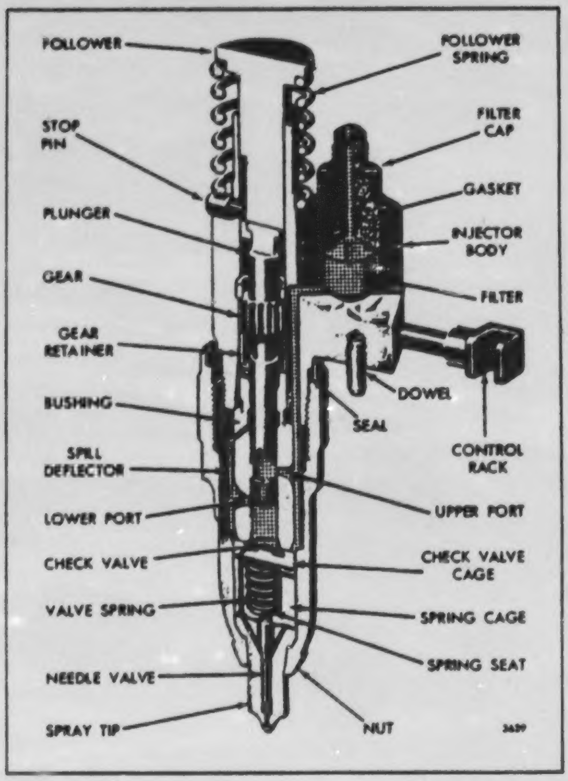

FOLLOWER
FOLLOWER SPRING
STOP PIN
FILTER CAP
GASKET
PLUNGER
INJECTOR BODY
GEAR
FILTER
GEAR RETAINER
DOWEL
BUSHING
SEAL
CONTROL RACK
SPILL DEFLECTOR
UPPER PORT
LOWER PORT
CHECK VALVE
CHECK VALVE CAGE
VALVE SPRING
SPRING CAGE
SPRING SEAT
NEEDLE VALVE
SPRAY TIP
NUT

Figure 4.6. Unit Injection Assembly.

The pump plunger receives its downward motion--the delivery stroke--from a fuel cam through a rocker arm which acts on the plunger follower. The plunger is returned by the plunger spring. The fuel, under a pressure of about 35 psi, is admitted through a small filter and fills the annular supply chamber around the pump plunger barrel, called a bushing. As the plunger moves downward, fuel is displaced into the supply chamber, at first through the lower port, and later, when the lower edge of the plunger closes this port, through a central and a transverse port or crosswise drilled holes in the plunger and the upper port. When the upper helical edge has covered the upper port, the fuel from the pump plunger barrel is forced down into the nozzle body, opening the spherical check valve, past the flat check valve, and into the spray tip. From there it is forced through the orifices into the cylinder. The fuel-injection pressure is raised to approximately 20,000 psi as the fuel passes through the nozzle. Injection continues until the lower helix on the plunger uncovers the lower port in the plunger barrel. The fuel then begins to bypass through the holes in the plunger and through the lower port into the supply chamber. This releases the pressure on the fuel in the plunger barrel, and the check valve spring causes the spherical check valve to seat. On the return stroke, the upward movement of the plunger fills the plunger barrel with fuel oil which flows from the supply chamber through the lower port. The function of the flat check valve is only to close the inside of the nozzle to keep combustion gases from entering the injector.

Turning of the plunger to change the effective length of the stroke is accomplished by a gear and rack connected to the governor or hand throttle. The middle part of the plunger has a hexagonal cross section which slides through a corresponding hole in the gear, thus forcing the plunger to turn with the gear. The effective stroke is determined by the relative positions of the helices and the upper and lower ports.

The advantage of the unit-injector construction is in the absence of long fuel lines which cause pressure waves and sometimes mechanical troubles. However, one disadvantage lies in the high pressures created. Such pressures result in faster wear of the spray orifices and necessitates dismantling a considerable part of the valve gear to take out one unit injector. Another disadvantage is the greater chance of fuel leaks into the engine sump and dilution of the lubricating oil.

4.7. DISTRIBUTOR SYSTEM

Of the several distributor systems used in different makes of engines, the only one in use at present in Army vessels is the Cummins system. Although essentially a distributor system, it has the characteristic features of a unit injector and is sometimes classified as such. In this system, fuel under pressure ranging from 130 psi to 150 psi is supplied by a gear transfer pump, as shown in figure 4.7, through an indexed rotating distributor, to a metering plunger during its downward stroke. This plunger has a variable stroke, controlled by the governor, and receives its upward motion from a multi-lobe cam and the downward motion by a spring. During the upward stroke, this plunger sends the fuel through other passages in the same distributor to the individual injectors on each engine cylinder. The fuel enters at the top of the injector, as illustrated in figure 4.7, flows through an inlet passage past a spring-loaded check valve, and fills the chamber under the injector plunger which, except at the end of injection, is off its seat. The injector plunger is operated by a cam through a rocker lever and link. As the fuel is delivered from the distributor to the injector during the suction stroke of the engine, the injector plunger is gradually lifted and the fuel fills the space in the cup under the plunger. At the time of injection, the plunger is pushed downward and the fuel prevented by the check valve from returning to the distributor is injected into the combustion space. It is finely atomized by being forced under a relatively high pressure through six small holes, 0.006 inch to 0.008 inch in diameter, depending upon the size of the engine.

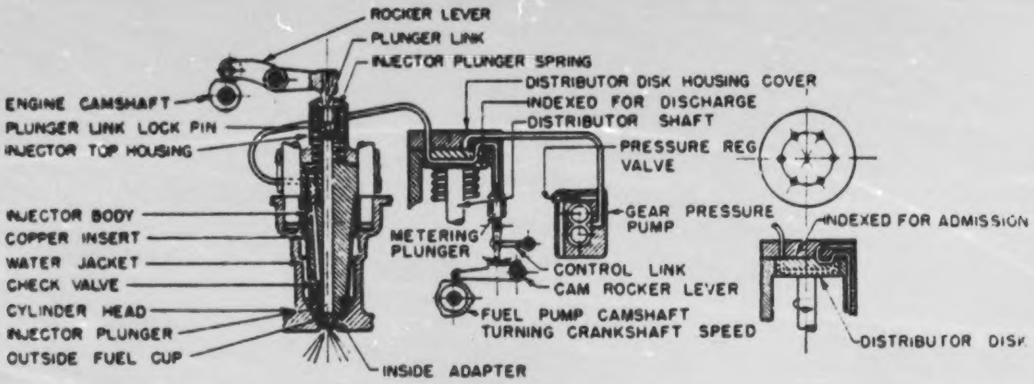

ROCKER LEVER
PLUNGER LINK
INJECTOR PLUNGER SPRING
DISTRIBUTOR DISK HOUSING COVER
INDEXED FOR DISCHARGE
DISTRIBUTOR SHAFT
ENGINE CAMSHAFT
PLUNGER LINK LOCK PIN
INJECTOR TOP HOUSING
PRESSURE REG VALVE
INJECTOR BODY
COPPER INSERT
WATER JACKET
CHECK VALVE
CYLINDER HEAD
INJECTOR PLUNGER
OUTSIDE FUEL CUP
METERING PLUNGER
GEAR PRESSURE PUMP
INDEXED FOR ADMISSION
CONTROL LINK
CAM ROCKER LEVER
FUEL PUMP CAMSHAFT TURNING CRANKSHAFT SPEED
DISTRIBUTOR DISK
INSIDE ADAPTER

Figure 4.7. Schematic of Cummins Distributor System.

The advantage of this system is the absence of high pressure lines and pressure waves. Its disadvantage is the relatively large inertia of moving parts, making it not suitable for very high speeds. Another disadvantage, more or less eliminated in the new type injector, is dilution of the lubricating oil in the engine crankcase because of leaking of fuel oil past and up the injector plunger.

4.9. SUMMARY

The diesel engine must have its fuel injected into its cylinder. The fuel injector has to fulfill the following requirements: metering, timing, rate of injection, atomization, and distribution. Fuel can be injected into the cylinder by three different systems, depending upon the type of engine--common-rail, individual-pump, or distributor system.

The basic common-rail system consists of a high pressure pump which discharges fuel into a common rail to which each fuel injector is connected by tubing. A spring-loaded bypass valve on the header maintains a constant pressure in the system, returning all excess fuel to the fuel supply tank. The individual pump system is designed to meet the demands of modern, high-speed engines. This system has two essential parts to each cylinder: the injection pump and the spray nozzle. The nozzles are either of the open or closed type. The open type usually is a simple spray nozzle with a check valve which prevents the high-pressure gases in the engine from passing to the pump. The closed type, the most commonly used, is basically a hydraulically operated, spring-loaded needle valve. The unit injector combines a fuel pump and spray nozzle in one unit or body. The distributor system is essentially the same as a unit injector.

Chapter 5

GOVERNORS

5.1. INTRODUCTION

To control an engine means to keep it running at a desired speed, either in accordance with or regardless of the changes in the load carried by the engine. The degree of control required depends upon the engine's performance characteristics and the type of load which it drives.

In diesel engines, a varying amount of fuel is mixed with a constant amount of compressed air inside the cylinder. A full charge of air enters the cylinder during each intake event. The amount of fuel injected into the cylinders controls combustion and thus determines speed and power output of a diesel engine. A governor regulates the flow of fuel.

5.2. TYPES OF GOVERNORS

Essentially a speed sensitive device, governors are designed to maintain a reasonably constant engine speed regardless of load variations. Since all governors used on diesel engines control engine speed by regulating the quantity of fuel delivered to the cylinders, they may be classified as speed regulating governors. They may also be classified according to the function or functions performed, the forces used in operation, and the means by which they adjust or move the fuel control mechanism.

The function a governor must perform on a given engine is determined by the load on the engine and the degree of control required. Subparagraphs *a* through *d* classify governors according to their use.

a. *Constant speed* governors maintain a constant engine speed regardless of load.

b. *Variable speed* governors maintain any desired engine speed between idle and maximum.

c. Speed limiting governors keep an engine from exceeding a specified maximum speed and from dropping below a specified minimum.

d. Load limiting governors limit the load the engine will handle at various speeds.

5.3. TERMS AND DEFINITIONS OF GOVERNORS

Before going into the operation of governors, study the following terms and their definitions so that you can better understand material this chapter discusses.

Hunting--continuous fluctuation of the engine speed (slowing down and speeding up) from the desired speed. Hunting is caused by overcontrol by the governor.

Isochronous governing--maintaining the speed of the engine truly constant, regardless of the load. This means governing with perfect speed regulation or zero speed drop.

Promptness--speed of action of the governor. It identifies the time interval required for the governor to move the fuel control mechanism from a no-load position to a full-load position. Promptness depends upon the power of the governor; the greater the power, the shorter the time required to overcome the resistance.

Sensitivity--change in speed required before the governor will make a corrective movement of the fuel control mechanism and is generally expressed as a percent of the normal or average speed.

Speed drop--decrease in speed of the engine from a no-load condition to a full-load condition. Speed drop is expressed in rpm, or more commonly as a percent of normal or average speed.

Stability--ability of the governor to maintain the desired engine speed without fluctuations or hunting.

5.4. OPERATING PRINCIPLES

In most of the governors installed on diesel engines used by the Army, the centrifugal force of rotating weights (flyballs) and the tension of a helical coil spring (or springs) are used in governor operation. On this basis, these governors are generally referred to as spring-loaded centrifugal governors.

In spring-loaded centrifugal governors, two forces oppose each other. One of these forces is the pressure of a spring (or springs) which may be varied either by an adjusting device or by moving the manual throttle. The other force is produced by the engine. Weights attached to the governor drive shaft are rotated and a centrifugal force is created when the shaft is driven by the engine. The magnitude of the centrifugal force varies directly with the speed of the engine.

Transmitted to the injectors through a connecting linkage, the pressure of the spring tends to increase the amount of fuel delivered to the cylinders. On the other hand, the centrifugal force of the rotating weights, through connecting linkage, tends to reduce the quantity of fuel injected. When the two opposing forces are equal or balanced, the speed of the engine remains constant.

To illustrate how the centrifugal governor works, assume that an engine is operating under load and that the opposing forces in the governor are balanced so that the engine speed is constant. If the load is increased, the engine speed decreases and a resultant reduction in the centrifugal force of the flyballs will take place. The spring pressure then becomes the greater force and it acts on the fuel control mechanism to increase the quantity of fuel delivered to the engine. The increase in fuel results in an increase in engine speed until balance of the forces is again reached.

When the load on an engine is reduced or removed, the engine speed increases and the centrifugal force within the governor increases. The centrifugal force then becomes greater than the spring pressure and acts on the fuel control linkage to reduce the amount of fuel delivered to the cylinders. This causes the engine speed to decrease until a balance between the opposing forces is again reached and engine speed becomes constant.

5.5. REGULATION OF FUEL CONTROL MECHANISMS

Governors may be classified according to the method by which the fuel control mechanisms are regulated. In some governors, the centrifugal force of the rotating weights regulates the fuel supply directly through a mechanical linkage which operates the fuel control mechanism. Other governors are designed so that the centrifugal force of the rotating weights regulates the fuel supply indirectly by moving a hydraulic pilot valve which controls oil pressure. Oil pressure is then exerted on either side of a power piston which operates the fuel control mechanism.

Governors which regulate the fuel supply directly (through mechanical linkage) are called mechanical governors; those which control the fuel supply indirectly (though oil pressure), hydraulic governors. Simple mechanical and hydraulic governors are shown in figures 5. 1 and 5. 2.

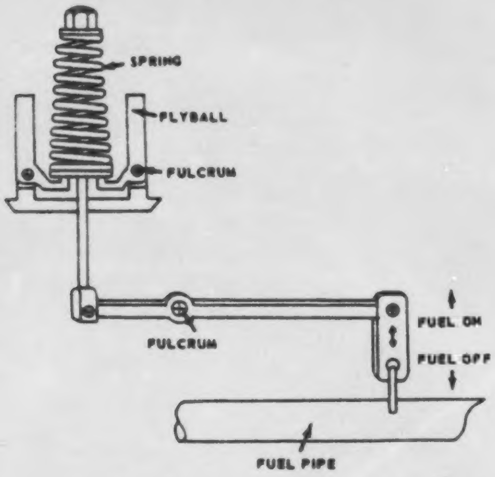


Figure 5. 1. Simple Mechanical Governor.

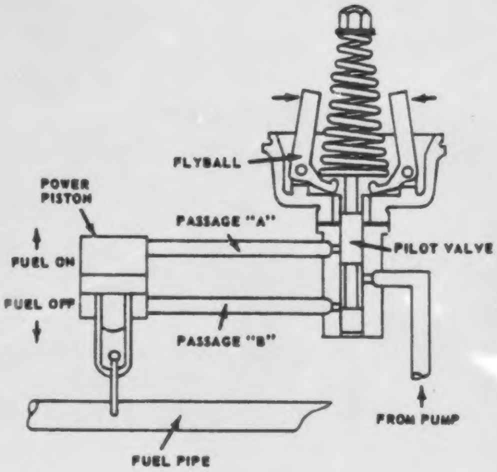


Figure 5. 2. Simple Hydraulic Governor.

Note that in the illustration of the mechanical governor, the weights (flyballs) are in an upright position. This indicates that the centrifugal force of the weights and the pressure of the spring are balanced; in other words, the engine is operating at constant load and speed.

In the illustration of the hydraulic governor, the positions of the parts indicate that the engine is responding to an increase in load with a resultant decrease in engine speed. Note that the weights tilt inward at the top. As engine speed decreases, the spring pressure overcomes the centrifugal force of these rotating weights. When the spring pressure is greater than the centrifugal force of the flyballs, the governor mechanism permits oil under pressure to force the piston to increase the fuel valve opening. The increased fuel supply causes an increase in engine power output and speed. The governor regulates the fuel supply so that sufficient power is developed to handle the increase in load.

There is always a lag between the moment that a change in fuel setting is made and the time the engine reaches the new desired speed. Even though the fuel controls are set as required during a speed change, hunting caused by overshooting will occur. As long as engine speed is above or below the desired speed, the simple hydraulic governor will continue to adjust (overcorrect) the fuel setting to decrease or increase the delivery of fuel. For this reason, a hydraulic governor must include a mechanism which will discontinue changing the fuel control setting slightly before the new setting required for sustaining the desired speed has actually been reached. The mechanism which accomplishes this process in all modern hydraulic governors is called a compensating device.

One type of compensating device is illustrated in figure 5.3. In the one illustrated, the pilot valve plunger operates in a movable pilot valve bushing in which are located the ports controlling the oil flow. The movement of the valve bushing during a speed change is controlled by the receiving compensating plunger. The compensating action of the valve bushing is controlled hydraulically by transfer and by leakage of oil between the compensating receiving plunger and the

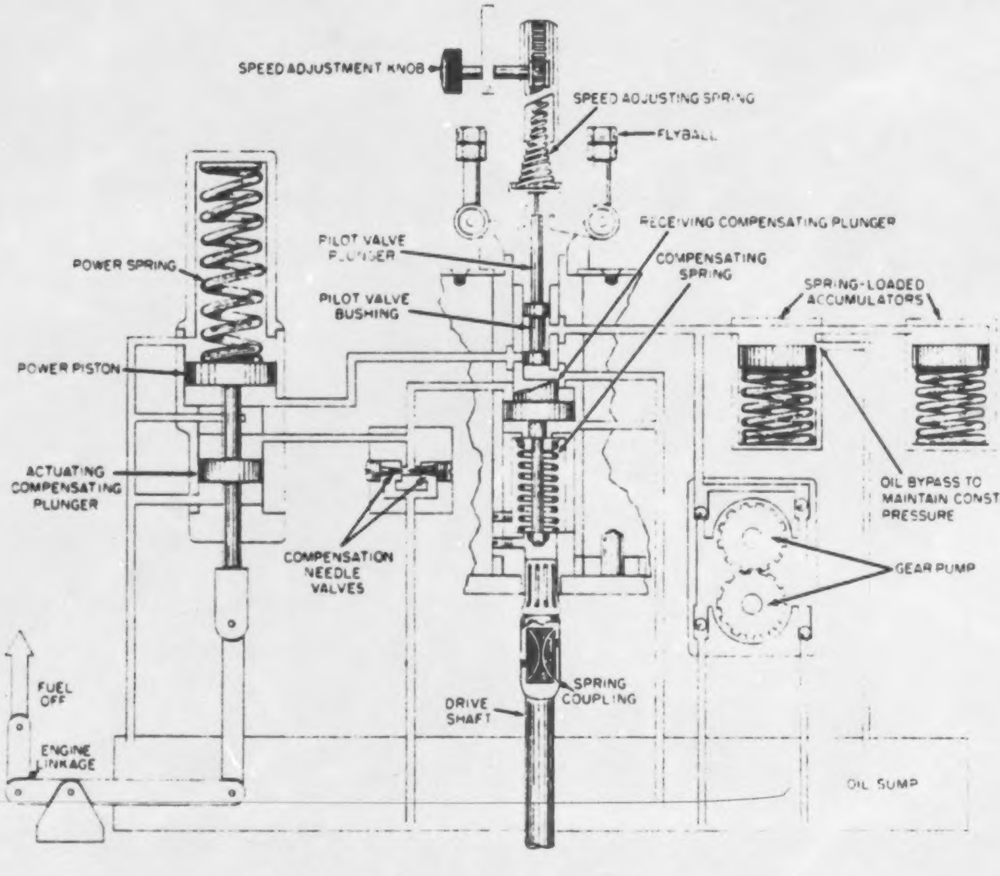

SPEED ADJUSTMENT KNOB
SPEED ADJUSTING SPRING
FLYBALL
RECEIVING COMPENSATING PLUNGER
COMPENSATING SPRING
PILOT VALVE PLUNGER
PILOT VALVE BUSHING
SPRING-LOADED ACCUMULATORS
POWER SPRING
POWER PISTON
ACTUATING COMPENSATING PLUNGER
COMPENSATION NEEDLE VALVES
OIL BYPASS TO MAINTAIN CONSTANT PRESSURE
GEAR PUMP
FUEL OFF
ENGINE LINKAGE
DRIVE SHAFT
SPRING COUPLING
OIL SUMP

Figure 5.3. Hydraulic Governor with Compensating Device.

compensating actuating piston. The rate of compensation is adjusted to fit the engine characteristics by regulating the oil leakage through the compensating needle valve. If the compensating needle valves are adjusted correctly, only a slight amount of hunting will occur following a load change. This hunting will quickly be dampened out, resulting in stable operation through the operating range of the governor.

Hydraulic governors are more sensitive than the mechanical ones. The design of a hydraulic governor enables a comparatively small governing unit to control the fuel mechanism of a large engine. The mechanical governor is more commonly found on small engines which do not require extremely close regulation of the fuel. Hydraulic governors are more suitable for larger engines in which more accurate regulation of fuel is necessary.

5.6. OVERSPEED SAFETY DEVICES

Engines maintained in proper operating condition seldom reach speeds above those for which they are designed. However, there may be times when conditions occur which may result in speeds becoming excessively high. The operation of a diesel engine at excessive speeds is extremely dangerous because of the relatively heavy construction of the engine's rotating parts. If the engine speed is sufficiently high, the inertia and centrifugal force developed may cause parts to become seriously damaged or even to fly apart. Therefore, it is essential that you know why an engine may reach a dangerously high speed, and how an engine may be brought under control when excessive speed occurs.

In some two-stroke-cycle engines, lubricating oil may leak into the cylinders as a result of leaky blower seals or broken piping. Even though the fuel is shut off, the engine may continue to operate, or even "run away," as a result of the combustible material coming from the uncontrolled source. Engines in which lubricating oil may accumulate in the cylinders are generally equipped with an automatically operated mechanism which suts off the intake air at the inlet passage to the blower. If an air shutoff mechanism is not provided and shutting off the fuel will not stop an engine which is overspeeding, anything which can be placed over the engine's intake to stop airflow will stop the engine. WARNING the component placed over the air intake must be large enough to overlap the air intake so it will not be drawn into the engine.

Excessive engine speeds are more commonly associated with an improperly functioning regulating governor rather than with lubricating oil accumulations in the cylinders. Whereas stopping the flow of intake air is used as a means of stopping an engine which is overspeeding because of lubricating oil in the cylinders, a means of shutting off or decreasing the fuel supply to the cylinders is more commonly used to accomplish an emergency shutdown or reduction of engine speed when the regulating governor fails to function properly.

Shutting off the fuel supply to the cylinders of an engine may be accomplished in various ways. The fuel control mechanism may be forced to the "no fuel" position; the fuel line may be blocked by closing a valve; the pressure in the fuel injection line may be relieved by opening a valve; or the mechanical movement of the injection pump may be prevented. These methods of shutting off fuel supply may be accomplished by either manual or automatic means.

Automatic operation of fuel and air control mechanisms is accomplished by overspeed safety devices. As emergency controls, these safety devices operate only in the event that the regular speed governor fails to maintain engine speed within the maximum design limit. Devices which function to bring an overspeeding engine to a full stop by completely shutting off the fuel or air supply are generally called overspeed trips. Devices which function to reduce the excessive speed of an engine, but allow the engine to operate at safe speeds, are more commonly called overspeed governors.

All overspeed governors and trips depend upon a spring-loaded centrifugal governor element for their operation. In overspeed devices, the spring tension is sufficiently great to overbalance the centrifugal force of the weights until the engine speed rises above the desired maximum. When an excessive speed is reached, the centrifugal force overcomes the spring tension and operates the mechanism which stops or limits the fuel or air supply.

When a governor serves as the safety device, the actual operation of the fuel or air control mechanism by the centrifugal force may be accomplished directly, as in a mechanical governor, or indirectly, as in a hydraulic governor. In an overspeed trip, the shutoff control is operated by a power spring. The spring is placed under tension when the trip is manually set and held in place by a latch. If the maximum speed limit is exceeded, a spring loaded centrifugal weight moves out and trips the latch, allowing the power spring to operate the shutoff mechanism. Overspeed safety devices must always be operative and must never be disconnected for any reason while the engine is operating.

5.7. SUMMARY

To maintain a regulated speed in a diesel engine, regardless of load, a governor must be installed. To maintain a constant speed under any load, a constant speed governor is used. To maintain any speed between idle and maximum speed, a variable governor is used. A speed limiting governor is used to keep an engine from exceeding a set maximum speed. A load limiting governor limits the load which an engine will handle at various speeds.

A governor may be classified according to the method by which the fuel control mechanisms are regulated. The governor that controls the fuel by the centrifugal force of rotating weights through a mechanical linkage is a mechanical governor. The hydraulic governor is designed so that the centrifugal force of the rotating weights regulates the fuel supply indirectly by moving a hydraulic pilot valve.

Appendix I

REFERENCES

Army Regulations

AR 310-25	Dictionary of United States Army Terms
AR 310-50	Authorized Abbreviations and Brevity Codes

Technical Manuals

TM 55-503	Marine Salvage and Hull Repair
TM 55-509	Marine Engineman's Handbook

Navy Publications

NAVPERS 16178-A	Fundamentals of Diesel Engines-U. S. Navy
NAVPERS 10541-A	Engineman 3 & 2

Appendix II

GLOSSARY

Accelerate--to increase the speed of movement, such as increasing the speed of a piston or flywheel.

Air injection--system of injecting fuel into the combustion chamber of a diesel engine by means of a blast of highly compressed air.

Alloy--combination of two or more metals mixable with each other when molten.

Annular--having a ring form.

Babbit--soft alloy of tin, copper, and antimony used to line bearing shells.

Bearing--support for a revolving shaft or a moving surface.

Bed plate--lower part of the engine resting on the foundation.

Bore--interior diameter of an engine cylinder.

Bottom dead center (b.c.)--farthest distance a piston can travel in a cylinder from the cylinder head.

Bushing--brass or bronze liner forced into a boared hole to provide a better wearing surface or one that may be easily renewed when worn.

Cam--piece attached to a shaft, a portion of which is circular, the remainder (the nose) protruding beyond this circle. Cams are used to impart a desired motion to poppet valves.

Camshaft--shaft which carries the various cams required for the operation of inlet, exhaust, fuel, and starting-air valves.

Cam follower--part of the push rod that is in contact with the cam.

Carbon steel--term applied to such steels that contain carbon alone as distinguished from other alloy steels.

Casting--metallic object formed by running molten metal into a mold of sand or plaster, which has previously been prepared from a mold or pattern.

Cast iron--metal produced in a blast furnace and useful because of the ease with which it can be melted and cast into a mold.

Centrifugal force--force acting on all parts of a rotating body that tends to pull them away from the axis of rotation.

Check valve--valve that permits the passage of a liquid or gas in one direction. It stops, or checks, reverse flow.

Chromium--grayish white metal, hard and brittle, and resistant to corrosion.

Combustion--rapid oxidation or combination of a combustible such as carbon, hydrogen or sulfur, with oxygen.

Common rail--pipe or header from which branch lines lead to each of the fuel valves in the different cylinder heads of a diesel engine and in which fuel is carried at high pressure, ready for delivery to each separate cylinder when the fuel valve is opened by a cam.

Compression--act or result of pressing a substance into a smaller space. One of the events of an internal combustion-engine cycle.

Compression ignition--ignition of a fuel charge by the heat of the air in a cylinder, generated by compression of air, as in the diesel engine.

Compression ratio--ratio of the volume of the charge in the engine cylinder at the beginning of the compression stroke to that at the end of the compression stroke.

Compression rings--piston rings placed in the upper part of a piston to seal against loss of compression pressure and against gas blowing.

Compression stroke--stroke of the piston during which the air change in the cylinder is compressed by the piston movement.

Concave--depressed or indented with curved lines.

Connecting rod--engine part which connects the piston to the crankshaft. It changes reciprocating motion of the piston into rotary motion of the crankshaft or vice versa.

Connecting rod bearing--bearing located in the large end of the connecting rod by which it is attached to the crankshaft.

Constant-pressure combustion--combustion of fuel in a cylinder at so slow a rate that there is no rise in cylinder pressure.

Constant-volume combustion--combustion in a cylinder so fast that there is no change in volume.

Contraction--becoming smaller in size. In metals and fluids a result of cooling or a lowering of temperature.

Convex--a rounded outward surface.

Crank--part of the crankshaft which is in the form of a crank and crankpin.

Crankcase--middle part of the engine structure surrounding the working parts.

Crankpin--part of the crank to which the connecting rod is attached.

Crankshaft--part of the engine which transmits the reciprocating motion of the pistons to the driven unit in the form of rotary motion.

Crankshaft cheek--part of the crankshaft that connects the crankpin to the main crankshaft journal.

Crankshaft journal--part of the crankshaft which rotates in the main bearings and transmits the torque developed by the engine.

Crankshaft web--crankshaft cheek.

Crosshead--part of an engine to which are attached the piston pin with the connecting rod and the piston rod, and which is supported on guides.

Crown--top of a piston.

Cycle--series of events that repeat themselves in a regular sequence.

Cylinder--cylindrical part of the engine in which the piston moves and combustion takes place.

Cylinder block--a number of cylinders cast in one piece.

Cylinder head--part which covers and seals the end of the cylinder and usually contains the valves.

Cylinder liner--cylindrical lining that is inserted into the cylinder jacket or cylinder block in which the piston slides.

Diesel engine--compression-ignition internal combustion engine first developed by Rudolf Diesel.

Distributor--device which distributes and directs the flow of fuel or compressed air to the various cylinders of the engine in proper sequence.

Eccentric--circle not having the same center as another circle within it.

Efficiency--ratio of output over input.

Elasticity--ability of an object to return to its original shape after it has been stretched.

Energy--capacity for doing work.

Engine--machine which produces power to do work, particularly one that converts heat into mechanical work.

Exhaust--act of discharging gases from an engine after they have done work.

Exhaust manifold--pipe that collects the burned gases as they are expelled from the cylinders.

Exhaust valve--valve through which the burned gases are allowed to pass out to the exhaust manifold.

Feeler gauge--shop tool for gauging or measuring the distance between two abutting surfaces.

Fluctuation--variation in value, such as of pressure or velocity.

Flywheel--wheel on the end of the crankshaft which gives the crankshaft momentum to carry the pistons through the compression stroke.

Four-stroke engine--engine operating on a cycle which is completed in four strokes, or two revolutions of the crankshaft.

Friction--resistance to relative motion between two bodies in contact.

Fuel injector--device which sprays the fuel into the cylinder.

Flyballs--weights in a centrifugal governor.

Gasket--packing placed between two surfaces that must have a leak-proof joint.

Governor--mechanism used to control the speed of an engine.

Helix--a line cut on a cylindrical surface shaped like a screw thread.

Hexagonal--having six sides.

Horizontal--parallel to the horizon.

Hydraulics--science relating to liquids in motion and dealing with their useful application.

Inertia--tendency of a body to maintain its existing velocity.

Injection--forcing fuel oil into the combustion chamber of a diesel engine by means of high pressure.

Injection pump--pump used to inject fuel oil into the combustion space of a diesel engine.

Inlet valve--valve through which air or the air-fuel mixture is admitted to the cylinder of a four-stroke engine.

Integral--indivisible part of a whole, constituting a completed work.

Jerk pump--fuel pump which injects fuel into the cylinder by action of a cam having a sharp nose.

Journal--finished part of a shaft that rotates in a bearing.

Key--square or rectangular piece of steel, straight or tapering from one end to the other, used to secure a part on a shaft.

Keyway--machined slot in a shaft or hub of a wheel to take a steel key.

Kinetic energy--energy of a moving body because of its mass and velocity.

Land--portion of the piston between two grooves carrying the piston rings.

Lanova cell--special combustion chamber, also called energy cell, for engines of high rotary speeds.

Lubricant--liquid or grease employed to separate two surfaces in relative motion to each other, to reduce friction.

Manifold--pipe with a number of inlets to or outlets from the several cylinders of an engine.

Mechanical injection--injection with the fuel-valve operated mechanically from a cam.

Needle valve--round steel rod with a conical or tapered point that seats against an outlet and prevents fuel oil from entering the engine cylinder except when it is lifted by a cam or oil pressure.

Nozzle--part of the injector or spray valve in which are located the holes through which the fuel is injected into the cylinder.

Oil-control rings--piston rings, usually located at the lower part of the piston, that prevents an excessive amount of lubricating oil from being drawn up into the combustion space during the suction stroke.

Oil grooves--passages cut in bearings for distributing the lubricating oil.

Opposed-piston engine--engine that has two pistons within the same cylinder traveling in opposite directions.

Orifice--small round opening, usually refers to the hole in a spray nozzle.

Plunger--long piston of a single-acting pump, such as a fuel-injection pump.

Poppet valve--valve opened by the action of a cam and closed by a spring.

Power--rate at which work is performed.

Push rod--rod that transmits the action of a cam-operated valve.

Reciprocating--having a back-and-forth or up-and-down linear motion, such as a piston.

Relief valve--valve held closed by a spring and forced open when the pressure in the system rises above the desired height.

Resistance--mechanically, a force opposing the motion of a body, measured in pounds.

Ring grooves--grooves cut in the piston's external surface to hold the piston ring.

Rocker arm--lever that transmits the action of the cam, usually by means of push rod, to the stem of the intake or exhaust valve, also to the air starting valve and fuel injector.

Scavenging--removing from the engine cylinder, by a stream of slightly compressed air, the products of combustion of the preceding cycle.

Oscillate--moving back and forth; vibrating, swinging like a pendulum.

Pintle--small extension of the needle-valve tip projecting through the spray nozzle.

Piston--cylindrical part which reciprocates in the cylinder bore of an engine and transmits the force of the gas pressure through the connecting rod to the crankshaft.

Piston head--top of the piston or that part of the piston against which the gas pressure acts.

Piston pin--pin which rests in two bored holes in the piston and passes through the eye of the connecting rod to join the two together flexibly.

Piston-pin bearing--bearing either in the eye of the connecting rod or in the bored bosses of the piston, in which the piston pin rocks.

Piston-pin boss--part of the piston on the inside through which the hole is made to take the piston pin.

Piston ring--split ring placed in a groove of the piston to form a leakproof joint between the piston and the cylinder wall.

Piston skirt--part of the piston below the piston-ring grooves.

Piston stroke--movement of the piston from one end to the other of the piston travel in the cylinder bore.

Seal--any device to prevent leakage of gas or liquid, oil or water.

Shaft--round bar of steel or other strong metal that is used to transmit rotary action.

Shell--steel or bronze backing to which the babbit of a shaft bearing is bonded.

Sludge--tarlike formation in oil resulting from the oxidation of a portion of the oil.

Solid injection--rather misleading term applied to airless injection.

Speed droop--difference in speed between no-load and full-load engine speed.

Spray valve--fuel injector.

Supercharging--supplying of combustion air to an engine at higher than atmospheric pressure.

Tangential force--component of the force applied to the piston acting at a right angle to the crank arm.

Tappet--part of the valve-actuating mechanism in contact with the cam; the cam follower.

Thermal efficiency--percentage of the total chemical energy in the fuel consumed that is converted into useful work.

Throw of crankshaft--distance between the center of the crankpins and the center of the journals of the crankshaft. It is equal to half the stroke of the engine.

Timing--angle made by the crank with its top or bottom dead-center position at which some valve opens or closes.

Timing chain--chain used to connect the crankshaft and camshaft by which the camshaft is made to rotate.

Timing gears--gears keyed to the crankshaft and camshaft by which the camshaft is made to rotate.

Tolerance--allowable variation in dimensions.

Top dead center (t.c.)--position of the piston when it has completed its compression stroke.

Torque--effect which rotates or tends to rotate a body. It is measured in foot-pounds or foot-inches.

Turbulence--high-velocity swirling of air, fuel vapor, or a mixture of both within the combustion chamber or cylinder.

Two-stroke engine--engine operating on a cycle that is completed in two strokes, or one revolution of the crankshaft.

Valve--in a combustion engine, an intake or exhaust valve usually consists of a disk with a stem which is opened by a cam and closed by a spring.

Valve seat--part of the valve mechanism upon which the valve face rests to close the port.

Valve spring--spring used to close a valve.

Velocity--rate of motion or the speed of a body at any instant, measured in feet per minute (fpm) or revolutions per minute (rpm).

Wrist pin--piston pin.

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CORRESPONDENCE COURSE OF THE
U. S. ARMY
TRANSPORTATION SCHOOL

BASIC PRINCIPLES OF MARINE DIESEL ENGINES

LESSON EXERCISES
TRANS SUBCOURSE 475

8-2

Fort Eustis, Virginia

July 1972

TRANS SUBCOURSE 475

BASIC PRINCIPLES OF MARINE DIESEL ENGINES

INTRODUCTION

As a marine engineer you must understand the operating principles of diesel engines. The operating cycle of diesel engines can be divided into two types: the four-stroke and two-stroke. All diesel engines operate on one of these two cycles. The internal parts remain about the same between diesel engines. Since this is a basic course, the auxiliary components of diesel engines are not covered.

The purpose of this subcourse is to acquaint you with the operating cycles and systems that make up a diesel engine. It consists of two lessons and an examination, divided as follows:

	Credit hours
Lesson 1, Diesel Engine Construction, Principles, and Structural Parts	2
2, Valve Gear, Fuel Injection, and Governors	2
Examination	1
Total	5

You are not limited as to the number of hours you may spend on the solution of any lesson or the examination of this subcourse. For statistical purposes you are requested to enter on the answer sheet the number of hours spent on the solutions.

Text and materials furnished: Reference Text 475, Basic Principles of Marine Diesel Engines, July 1972.

When you have completed this subcourse, you keep the reference text and all lesson assignment sheets; do not return them with your answer sheets.

LESSON 1	Diesel Engine Construction, Principles, and Structural Parts.
CREDIT HOURS	2.
TEXT ASSIGNMENT	Reference Text 475, pars. 1.1-2.13.

MATERIALS REQUIRED . . . . None.

LESSON OBJECTIVE . . . . . . To enable you to identify the various types of diesel engines and their various parts and describe their operating principles.

SUGGESTIONS . . . . None.

EXERCISES

Detach the consolidated answer sheet and enter your solutions in the space provided for this lesson. Retain the answer sheet to use with succeeding lessons.

Weight **True-False**

(Mark "X" under A for true or under B for false.)

3 1. Wet liners have their own permanently shrunk-on jacket around the outside for the circulating cooling water.

3 2. Improved combustion can be obtained by creating air turbulences in the cylinder.

3 3. In a two-stroke engine the cylinder delivers one power stroke for every revolution of the crankshaft.

3 4. It is difficult to make a rigid crankshaft for an in-line engine of over eight cylinders.

3 5. The advantage of uniflow scavenging is that exhaust gases and scavenge air flow in opposite directions.

3 6. During the intake stroke of a four-stroke diesel engine, the piston creates a vacuum in the cylinder.

3 7. Babbit is made of soft steel and carbon.

3 8. Gold seal rings have a very small ring of gold bonded on their outer surface to provide a good seal between the ring and the cylinder wall.

3 9. In diesel engines the fuel is sprayed into the cylinder when the piston is at top dead center.

Weight

3 10. The diameter of the piston at the boss is slightly larger than the rest of the piston.

3 11. The piston crowns of most marine diesel engines are concave in shape.

Matching

Match the terms in column II with the definitions in column I by marking "X" in the appropriate space on the answer sheet. Items in column II may be used once, more than once, or not at all.

Weight		Column I		Column II
3	12.	Transmits reciprocating motion of the piston to the crankshaft.	A.	Main journal bearing.
			B.	Cylinder head.
3	13.	Point of support and center of rotation for the crankshaft.	C.	Land.
3	14.	Portion of a piston between two grooves.	D.	Connecting rod.
3	15.	The stationary part that seals one end of the combustion space.		

Multiple Choice

(Each question in this group contains one and only one correct answer. Make your choice by marking "X" in the proper space on the answer sheet.)

5 16. To help reduce the amount of air not reached by the fuel particles, what is needed?

A. Supercharging.
B. Scavenging.
C. Turbulence.
D. Compression.

Weight

5 17. Forcing air into the cylinder is known as:

A. Turbulence.
B. Compression.
C. Vacuum.
D. Supercharging.

5 18. The time lag requiring an advance of the fuel injection several crank-angle degrees before top dead center is called:

A. Valve lag.
B. Ignition delay.
C. Combustion delay.
D. Compression lag.

5 19. The point on a crankshaft that serves as a point of support and center of rotation is known as a:

A. Crankthrow.
B. Crankcheek.
C. Main bearing journal.
D. Crankpin.

5 20. The part that links the piston with the crankshaft is the:

A. Crankpin.
B. Pushrod.
C. Connecting rod.
D. Crosshead guide.

5 21. The inside diameter of the cylinder liner is known as the:

A. Crown.
B. Stroke.
C. Liner.
D. Bore.

5 22. To obtain efficient, smokeless combustion, two operations are necessary, atomization of the fuel and:

A. Supercharging.
B. Turbulence.
C. Scavenging.
D. Injection lag.

Weight

5 23. Only double-acting diesels require a:

A. Crosshead.
B. Babbit.
C. Spray nozzle.
D. Connecting rod.

5 24. The concave shape of a piston crown helps create:

A. Supercharging.
B. Atomization.
C. Turbulence.
D. Compression.

5 25. Gold seal rings have ________________ inserts.

A. Gold.
B. Bronze.
C. Babbit.
D. Gray cast iron.

5 26. In a four-stroke diesel engine the air charge is compressed in which of the four-stroke cycle?

A. First.
B. Second.
C. Third.
D. Fourth.

LESSON ASSIGNMENT SHEET

TRANS SUBCOURSE 475.	Basic Principles of Marine Diesel Engines.
LESSON 2	Valve Gear, Fuel Injection, and Governors.
CREDIT HOURS	2.
TEXT ASSIGNMENT	Reference Text 475, pars. 3.1-5.7.
MATERIALS REQUIRED	None.
LESSON OBJECTIVE	To enable you to identify the various types of valve gear, fuel injection systems, and governors associated with marine diesel engines.
SUGGESTIONS	None.

EXERCISES

Enter your solutions on the consolidated answer sheet in the space provided for this lesson. Mail the answer sheet in the addressed envelope provided.

Weight

True-False

(Mark "X" under A for true or under B for false.)

3 1. On the distributor fuel injection system the fuel pressure can range from 90 psi to 120 psi.

3 2. A governor that maintains any desired engine speed between idle and maximum is called variable.

3 3. Spring-loaded centrifugal governors have two opposing forces.

3 4. Automatic valve-lash adjusters avoid the necessity of a clearance between the cam and the follower.

3 5. A bridge is used to open and close a single valve.

Weight

3 6. The compressibility of the fuel and the mechanical flexibility in a jerk pump retards the actual start of injection.

3 7. As the speed of an engine decreases, the spring pressure of the hydraulic governor overcomes the centrifugal force of the rotating weights.

3 8. Mechanical governors are more sensitive than hydraulic ones.

3 9. Valve springs open the valves in diesel engines.

3 10. When the seat is worn in a valve cage, the entire cage must be replaced.

3 11. Valves in diesel engines are mushroom shaped.

Matching

Match the terms in column II with the definitions in column I by marking "X" in the appropriate space on the answer sheet. Items in column II may be used once, more than once, or not at all.

		Column I		Column II
3	12.	Rotating weights of a governor.	A.	Wedge.
3	13.	Located between the cam and push rod mechanism of a common-rail fuel injection system.	B.	Tappet.
			C.	Flyballs.
3	14.	Lower end in contact with the cam through a follower.	D.	Push rod.
3	15.	Part of the valve-actuating mechanism in contact with the cam.		

Multiple Choice

(Each question in this group contains one and only one correct answer. Make your choice by marking "X" in the proper space on the answer sheet.)

Weight

5 16. The speed of action of a governor is called:

- A. Sensitivity.
- B. Speed drop.
- C. Stability.
- D. Promptness.

5 17. A mechanical valve-lash adjuster is incorporated in the:

- A. Valve bridge.
- B. Push rod.
- C. Camshaft.
- D. Valve stem.

5 18. In governors the amount of centrifugal force produced depends upon the engine's:

- A. Weight.
- B. Cylinders.
- C. Speed.
- D. Temperature.

5 19. The eccentric projection on a revolving disk that controls the operation of a valve in a diesel engine is a:

- A. Crankthrow.
- B. Cam.
- C. Gear.
- D. Needle valve.

5 20. When fuel is injected too late in the cycle, all the fuel is not burned until the piston is way into the ________________ stroke.

- A. Intake.
- B. Power.
- C. Compression.
- D. Exhaust.

5 21. In the common-rail system, fuel is delivered from the fuel pump to the:

- A. Cylinder.
- B. Injector.
- C. Header.
- D. Filter.

Weight

5 22. An intake valve is usually made of:

A. Cast iron.
B. Nickel steel.
C. Aluminum.
D. Bronze.

5 23. To keep a hydraulic governor from hunting, a ____________ is installed.

A. Compensating device.
B. Needle valve.
C. Pressure regulating valve.
D. Wedge.

5 24. Governing with perfect speed regulation is ______________ governing.

A. Sensitive.
B. Speed droop.
C. Hydraulic.
D. Isochronous.

5 25. Measuring fuel for any given throttle setting is:

A. Metering.
B. Atomization.
C. Governing.
D. Fuel injection.

5 26. Valve springs are mounted between supports called:

A. Bridges.
B. Spring racks.
C. Spring seats.
D. Arms.

CORRESPONDENCE COURSE OF THE
U. S. ARMY
TRANSPORTATION SCHOOL

BASIC PRINCIPLES OF MARINE DIESEL ENGINES

EXAMINATION
TRANS SUBCOURSE 475

8-2

Fort Eustis, Virginia July 1972

EXAMINATION

TRANS SUBCOURSE 475.	Basic Principles of Marine Diesel Engines.
CREDIT HOURS	1.
TEXT ASSIGNMENT	All previous assignments.
MATERIALS REQUIRED	None.

SUGGESTIONS

Before starting this examination, fill out the information required on the answer sheet. Please complete the attached student's comment sheet and return it with your answer sheet.

EXERCISES

MULTIPLE CHOICE: Read each statement carefully and select the appropriate solution. On the answer sheet, mark "X" in the space under the letter that corresponds to the solution you have chosen. One and only one answer is correct; if you mark more than one choice, the entire point value for the question will be deducted.

EXAMPLE: 1. Which of the following is an example of labeled cargo?

- A. First-class mail.
- B. Pilferable PX supplies.
- C. Explosives.
- D. Perishable foods.

Since "C" is correct, the answer sheet should be marked:

	A	B	C	D
1.	( )	( )	(X)	( )

1. A diesel engine, in-line, having six cylinders would have how many cranks or throws?

   A. 3.
   B. 6.
   C. 9.
   D. 12.

2. The two components that make a mechanical governor function are centrifugal force and ________________.

   A. Hydraulic fluid.
   B. Spring tension.
   C. Flyballs.
   D. Wedges.

3. The disadvantage of a two-stroke diesel engine is:

   A. High rate of fuel consumption.
   B. Heavy vibrations.
   C. Large amount of small working parts.
   D. High operating temperature.

4. The edge of the face of an oil control ring is often ________________ to provide a scraping edge.

   A. Undercut.
   B. Rounded.
   C. Sharpened.
   D. Hollowed.

5. Valve seat inserts are more commonly used with ________________ valves.

   A. Air.
   B. Exhaust.
   C. Intake.
   D. Fuel injection.

6. Allowing the air charge to enter the cylinder under pressure is called:

   A. Scavenging.
   B. Turbulence.
   C. Supercharging.
   D. Uniflow.

7. The unit injector combines a pump and ______________ in the same body.

   A. Spray nozzle.
   B. Wedge.
   C. Header.
   D. Needle valve.

8. The pressure of the fuel is 20,000 psi as it passes through the nozzle of which injection system?

   A. Distributor.
   B. Common-rail.
   C. Jerk pump.
   D. Unit injector.

9. A bridge has special cams in contact with the:

   A. Valve stems.
   B. Push rod.
   C. Cam follower.
   D. Rocker arm.

10. To provide a sufficient cross-sectional area for heat flow, the piston crown is often:

    A. Made of a different metal.
    B. Made smaller.
    C. Made thicker than necessary.
    D. Hollow.

11. The degree of control an engine needs depends upon its performance characteristics and:

    A. Weight.
    B. Fuel consumption.
    C. Speed.
    D. Load.

12. The closed spray nozzle is ______________ operated.

    A. Mechanically.
    B. Push rod.
    C. Hydraulically.
    D. Valve.

13. The crankcase is often integral with the:

A. Cylinder block.
B. Tie bolt.
C. Oil pan.
D. Oil sump.

14. In opposed-piston engines all parts are easily accessible except the:

A. Lower crankshaft.
B. Camshaft.
C. Fuel header.
D. Oil pan.

15. Four-stroke diesel engines have at least _______________ cams for each cylinder.

A. 2.
B. 3.
C. 4.
D. 5.

16. To increase strength and minimize wear crankshafts are:

A. Chrome plated.
B. Finely ground.
C. Nitride treated.
D. Cast.

17. To increase the turbulence some cylinder heads have:

A. Air valves.
B. Energy cells.
C. Two nozzles.
D. Needle valves.

18. When a supercharger is applied to a four-stroke diesel engine, the _______________ timing is advanced.

A. Piston.
B. Intake-valve.
C. Injector.
D. Exhaust-valve.

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19. During the power stroke the gases force the rings down against the:

- A. Piston.
- B. Cylinder liner.
- C. Crown.
- D. Land.

20. Piston pins are made of:

- A. Cast-iron.
- B. Bronze.
- C. Hardened steel.
- D. Aluminum.

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CORRESPONDENCE COURSE OF THE
U. S. ARMY TRANSPORTATION SCHOOL
SOLUTIONS

TRANS SUBCOURSE 475. . . . . Basic Principles of Marine Diesel Engines

(All references are to Reference Text 475.)

LESSON 1

Weight	Exercise	Weight	Exercise
3	1. B, false. (par. 2.4c)	3	14. C. (par. 2.9)
3	2. A, true. (par. 1.18)	3	15. B. (par. 1.3)
3	3. A, true. (par. 1.16)	5	16. C. (par. 1.18)
3	4. A, true. (par. 1.10b(2))	5	17. D. (par. 1.19)
3	5. B, false. (par. 1.17)	5	18. B (par. 1.21)
3	6. A, true. (par. 1.13)	5	19. C. (par. 2.8)
3	7. B, false. (par. 2.5)	5	20. C. (par. 2.12)
3	8. B, false. (par. 2.10)	5	21. D. (par. 1.3)
3	9. B, false. (par. 1.13)	5	22. B. (par. 1.18)
3	10. B, false. (par. 2.9)	5	23. A. (par. 2.5)
3	11. A, true. (par. 2.9)	5	24. C. (par. 2.9)
3	12. D. (par. 1.5)	5	25. B. (par. 2.10)
3	13. A. (par. 2.8)	5	26. B. (par. 1.13)

All concerned will be careful that neither this solution nor information concerning the same comes into the possession of students or prospective students who have not completed the work to which it pertains.

LESSON 2

Weight	Exercise	Weight	Exercise
3	1. B, false. (par. 4.7)	3	14. D. (par. 3.4)
3	2. A, true. (par. 5.2b)	3	15. B. (par. 3.3)
3	3. A, true. (par. 5.4)	5	16. D. (par. 5.3)
3	4. A, true. (par. 3.7a)	5	17. A. (par. 3.7b)
3	5. B, false. (par. 3.4)	5	18. C. (par. 5.4)
3	6. A, true. (par. 4.4b)	5	19. B. (par. 3.2)
3	7. A, true. (par. 5.5)	5	20. B. (par. 4.2b)
3	8. B, false. (par. 5.5)	5	21. C. (par. 4.3)
3	9. B, false. (par. 3.6)	5	22. B. (par. 3.5)
3	10. B, false. (par. 3.5)	5	23. A. (par. 5.5)
3	11. A, true. (par. 3.5)	5	24. D. (par. 5.3)
3	12. C. (par. 5.4)	5	25. A. (par. 4.2a)
3	13. A. (par. 4.3)	5	26. C. (par. 3.6)